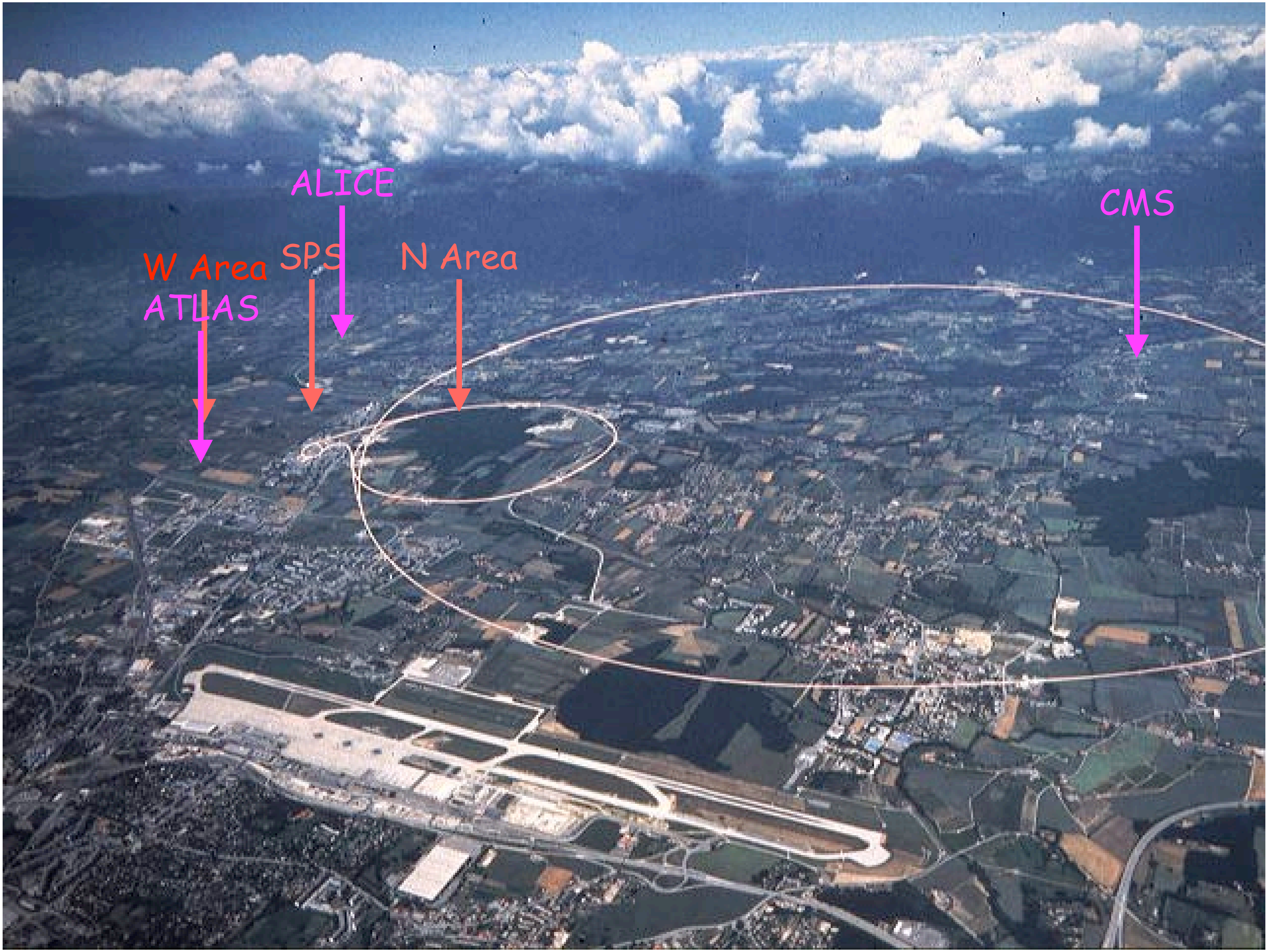
CERN Results and Future Prospects

T.C. Awes, ORNL

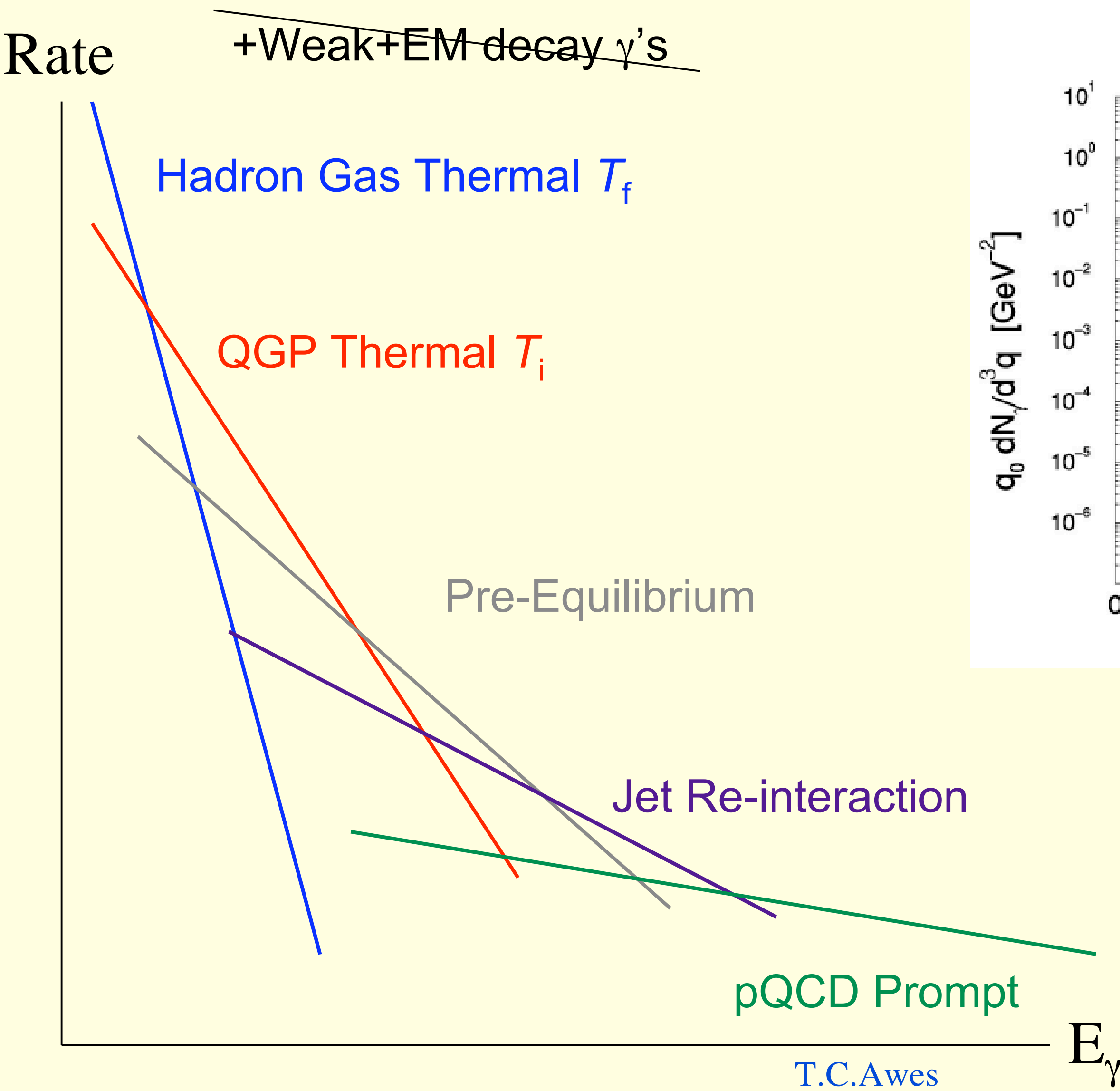
AGS Users Meeting,
EM Radiation / Low Mass Dileptons Workshop,
June 5, 2006

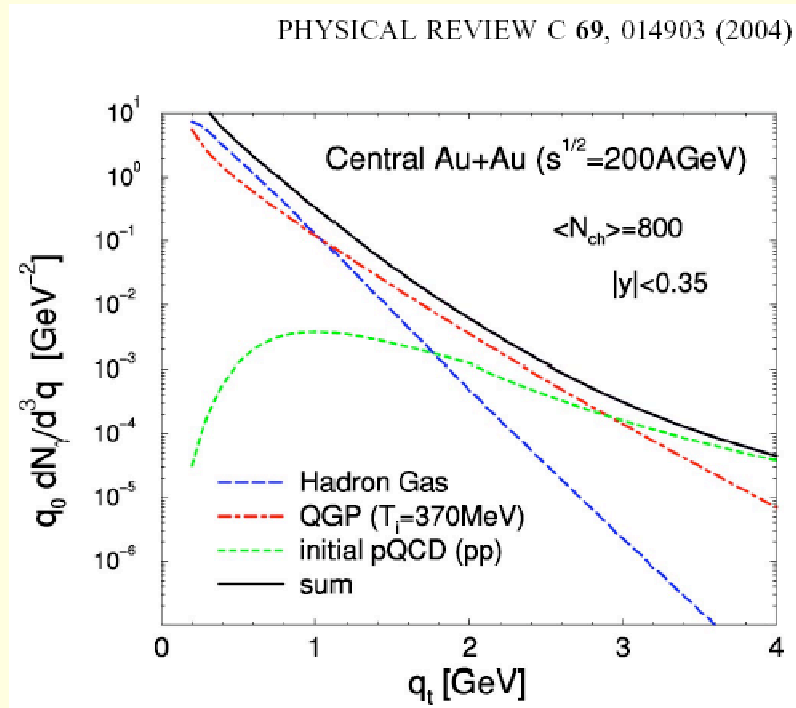
CERN results and future prospects

- Early Prospecting (SPS)
  - o Coming up empty
  - o Making something of nothing
  - o All that glitters is not gold
- Prospects for RHIC and the LHC


ALICE
CMS
W Area
SPS
N Area
ATLAS

Photons: Continuum Spectrum with Many Sources



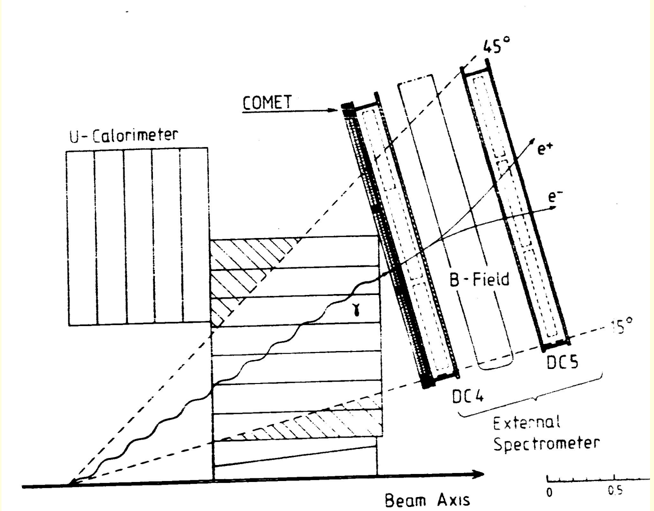


Turbide, Rapp, Gale

Final-state photons are the sum of emissions from the entire history of a nuclear collision.

First Results : Measuring Nothin'

HELIOS



p,O,S + Pt, W: Integral limit

γ/π^- in $0.1<p_T<1.5$ GeV/c

Z. Phys C **46**, 369 (1990)

WA80

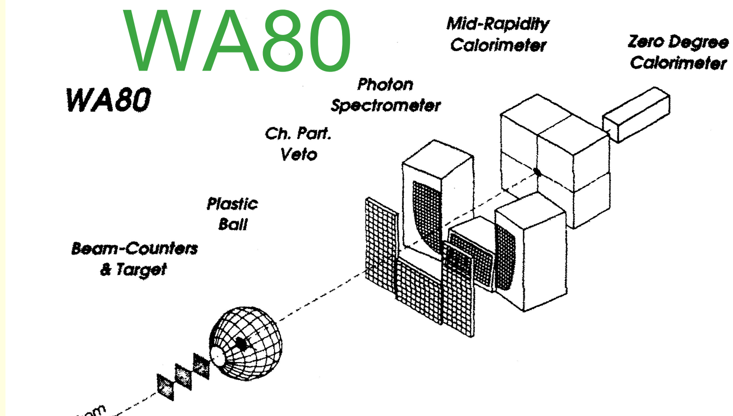
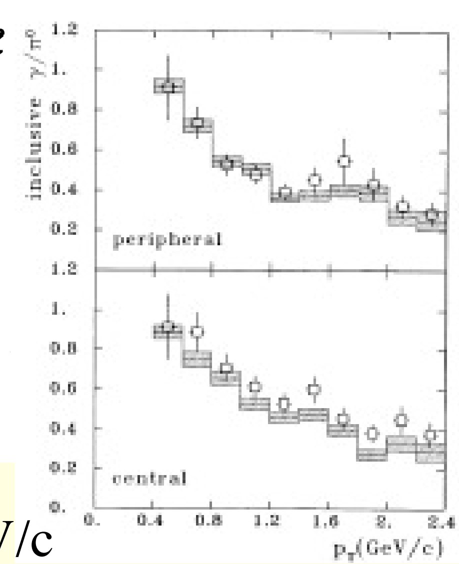


Fig. 1: WA80 Experimental setup



O + Au:

γ/π^0 in $0.4<p_T<2.4$ GeV/c

Z. Phys C **51**, 1 (1991)

CERES

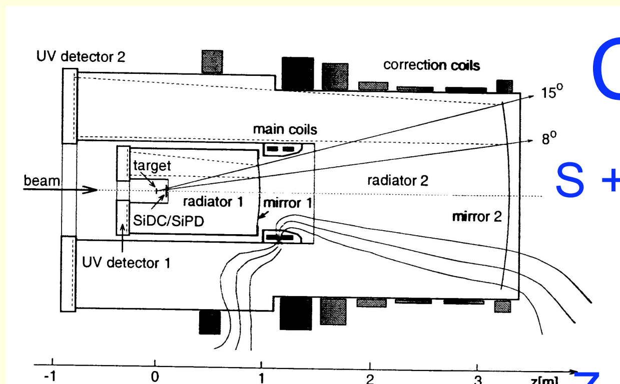


Fig. 1. Schematic view of the CERES spectrometer

S + Au: Integral limit

$\gamma/(dN^{Ch}/d\eta)$ in $0.4<p_T<2.0$ GeV/c

Z. Phys C **71**, 571 (1996)

Measuring "Nothing" better: First HI "Result"

- **Initial Expectations** (pre-experiment)**:**

(~Handwaving arguments..)

  *** Chiral symmetry restored**

  *** Lots of q+g scatterings**

  *** QM rates greater than HM** (false)

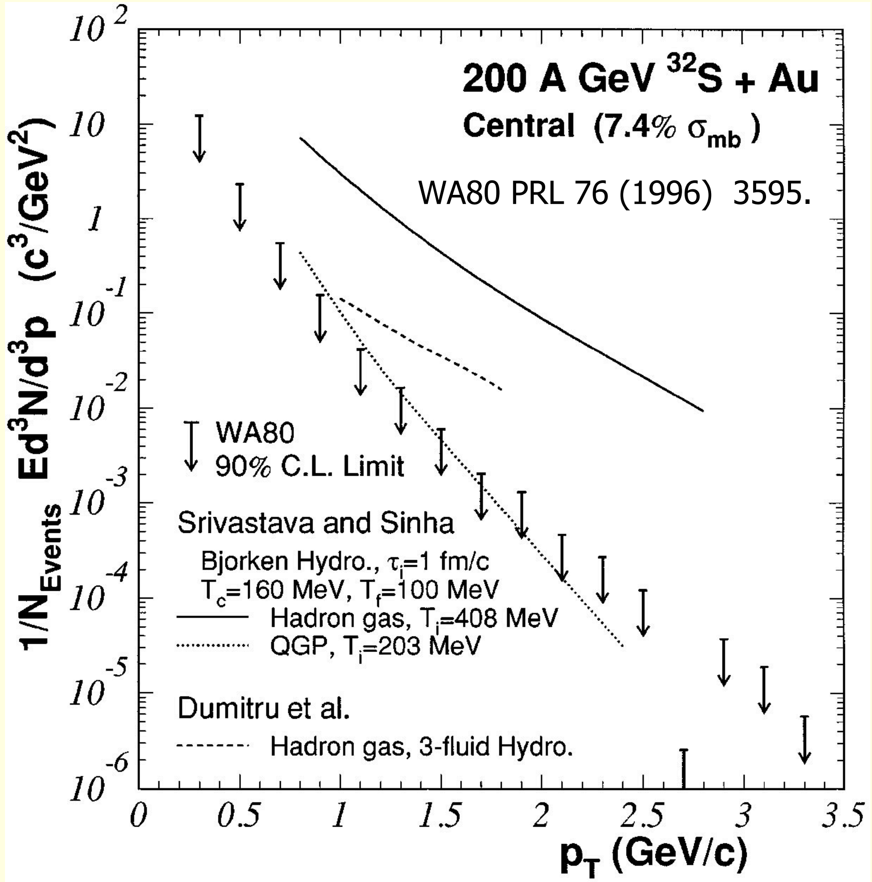
Expect lots of Thermal γ Radiation as a signature of Quark Gluon Plasma!

- **No γ excess observed in S+Au @SPS**

  *** If thermalized, result implies "low" initial Temperature.**

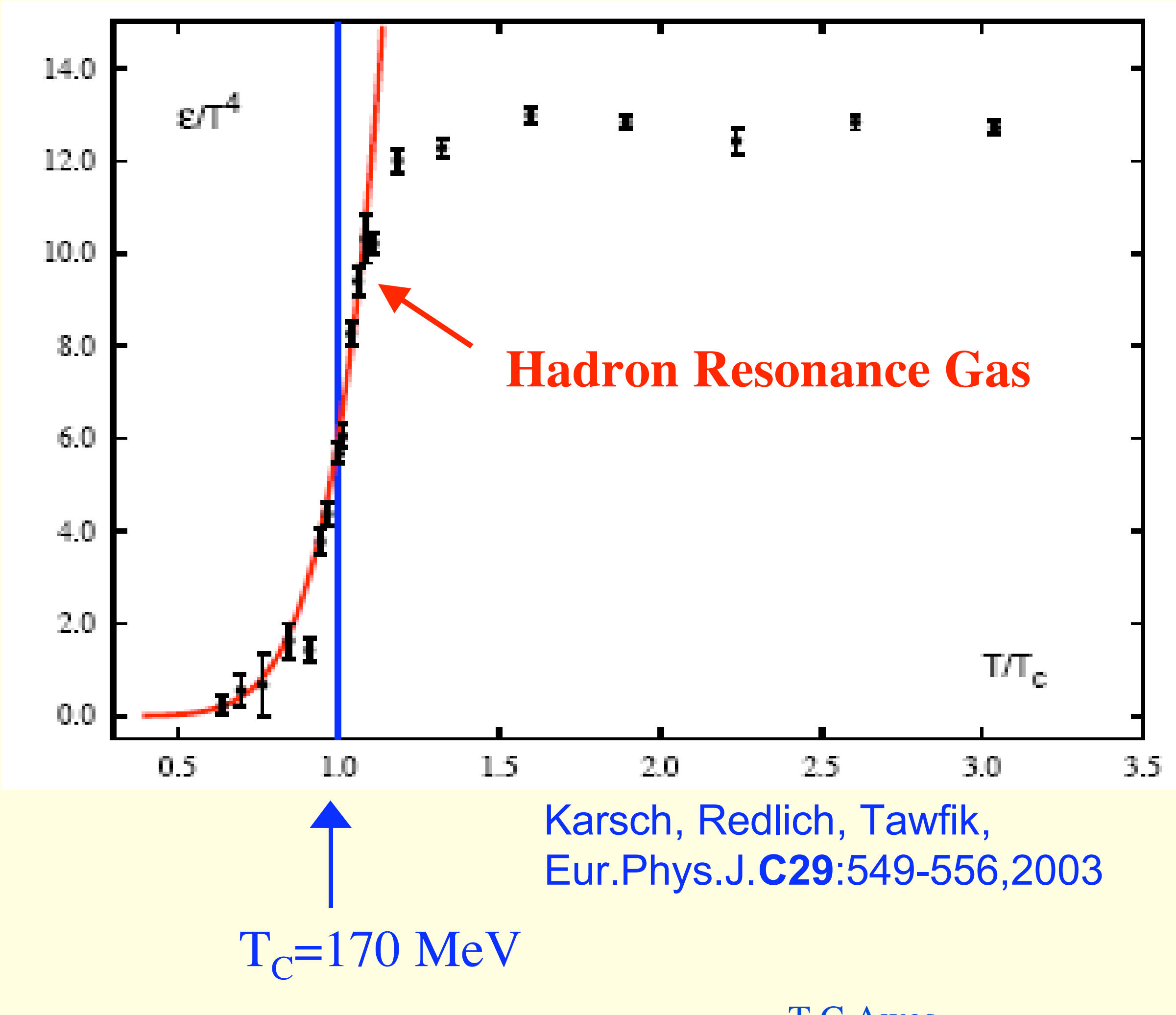
  *** Given large initial energy density, result implies large # d.o.f. As in a QGP!**

Lack of Thermal γ is a signature of QGP!



Ahh, but a π+ρ hadron gas is too naïve - Must consider d.o.f. of full hadron mass spectrum… It is a "significant" result - system produced has large number of d.o.f.

Deconfinement and High Energy Nuclear Collisions



Karsch, Redlich, Tawfik, Eur.Phys.J.**C29**:549-556,2003

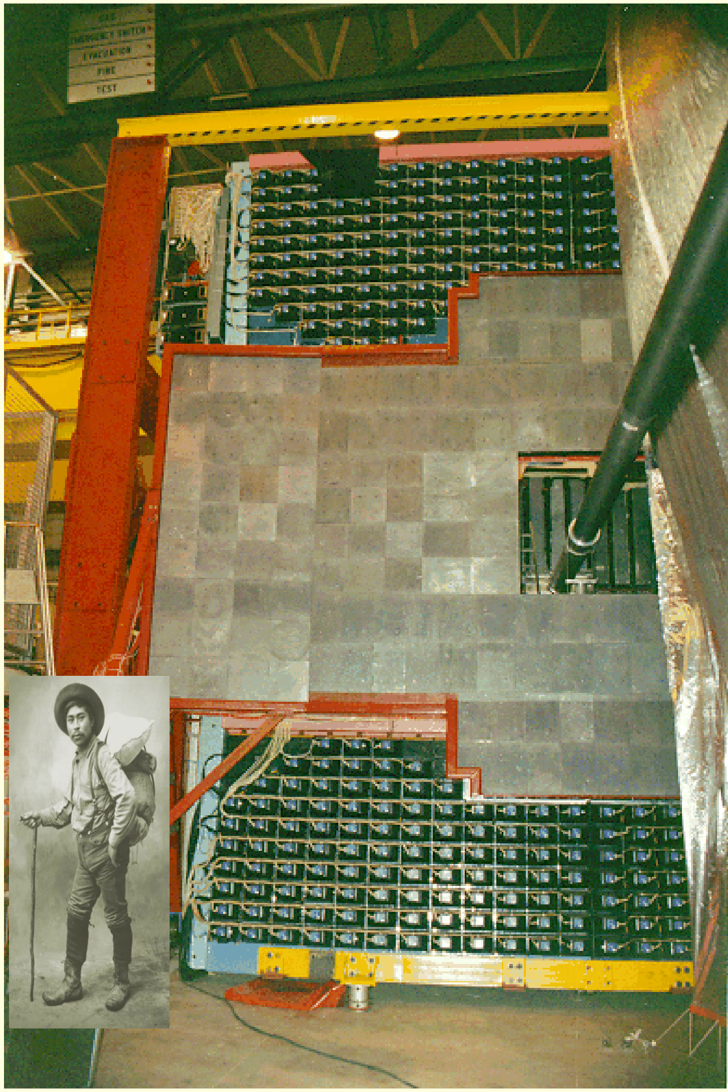
T_C=170 MeV

Lattice QCD predicts a sharp rise in the number of degrees of freedom (naively thought of as hadrons to quarks and gluons), the deconfinement phase transition.

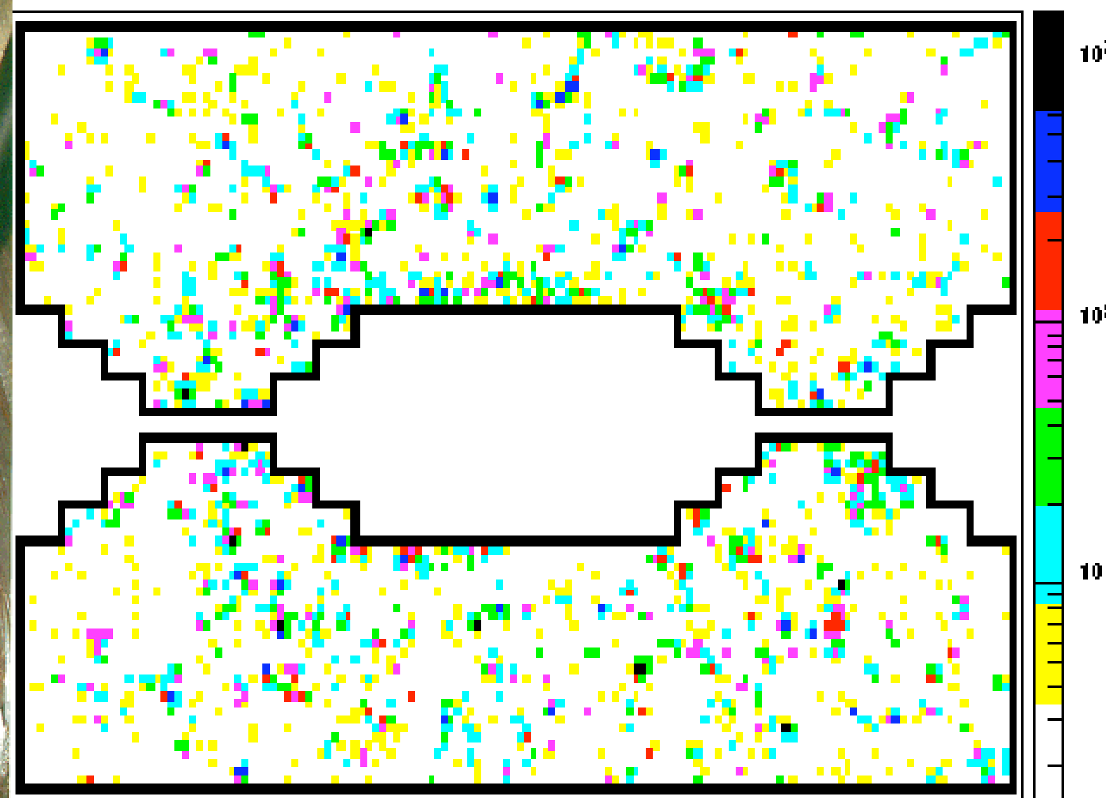
Pion gas is ruled out - but what about HRG?

Experimentally, a combination of energy density and temperature measurements (thermal γ radiation) can map out the transition.

Heavy Ions at SPS: Pb+Pb 158AGeV



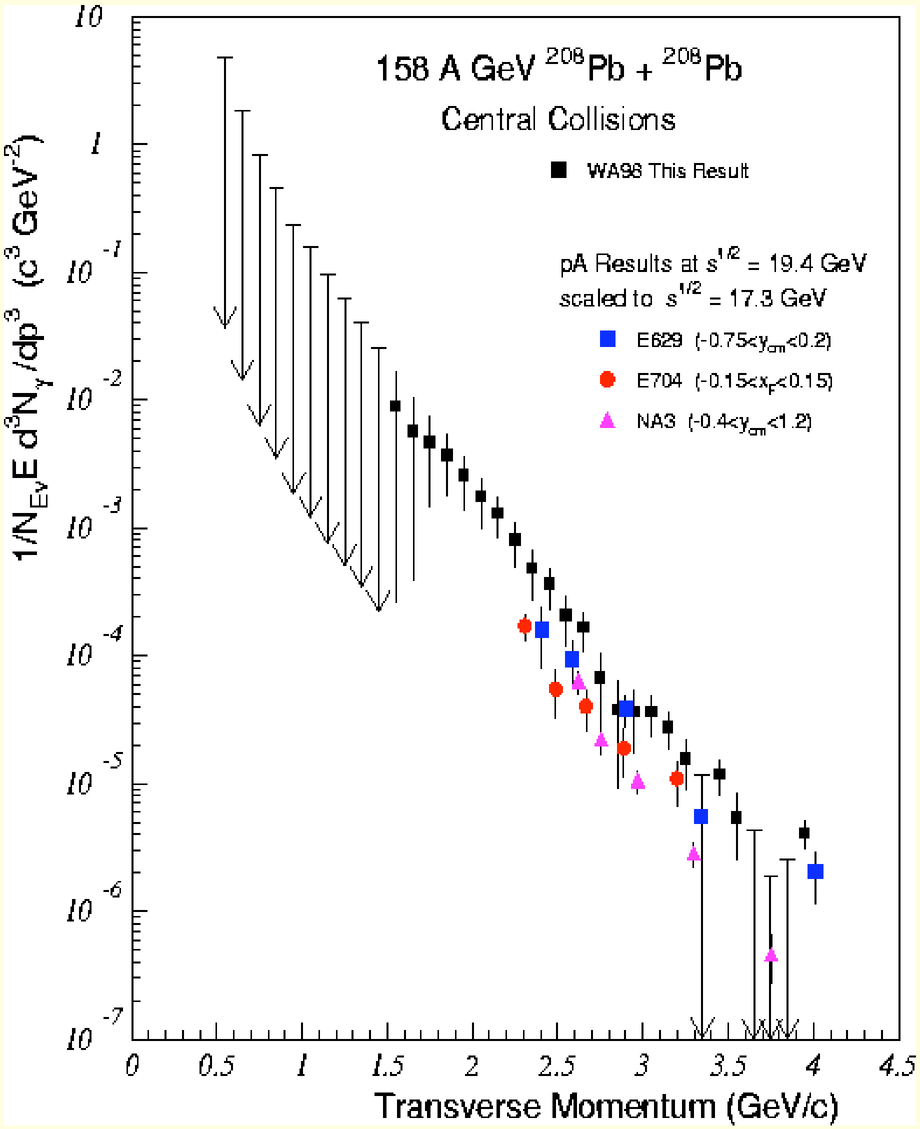
WA98 - LEDA event display



Pb + Pb 160 A GeV central

Nov. 3, 1995 - Run 0001 - Evt Nr. 00001

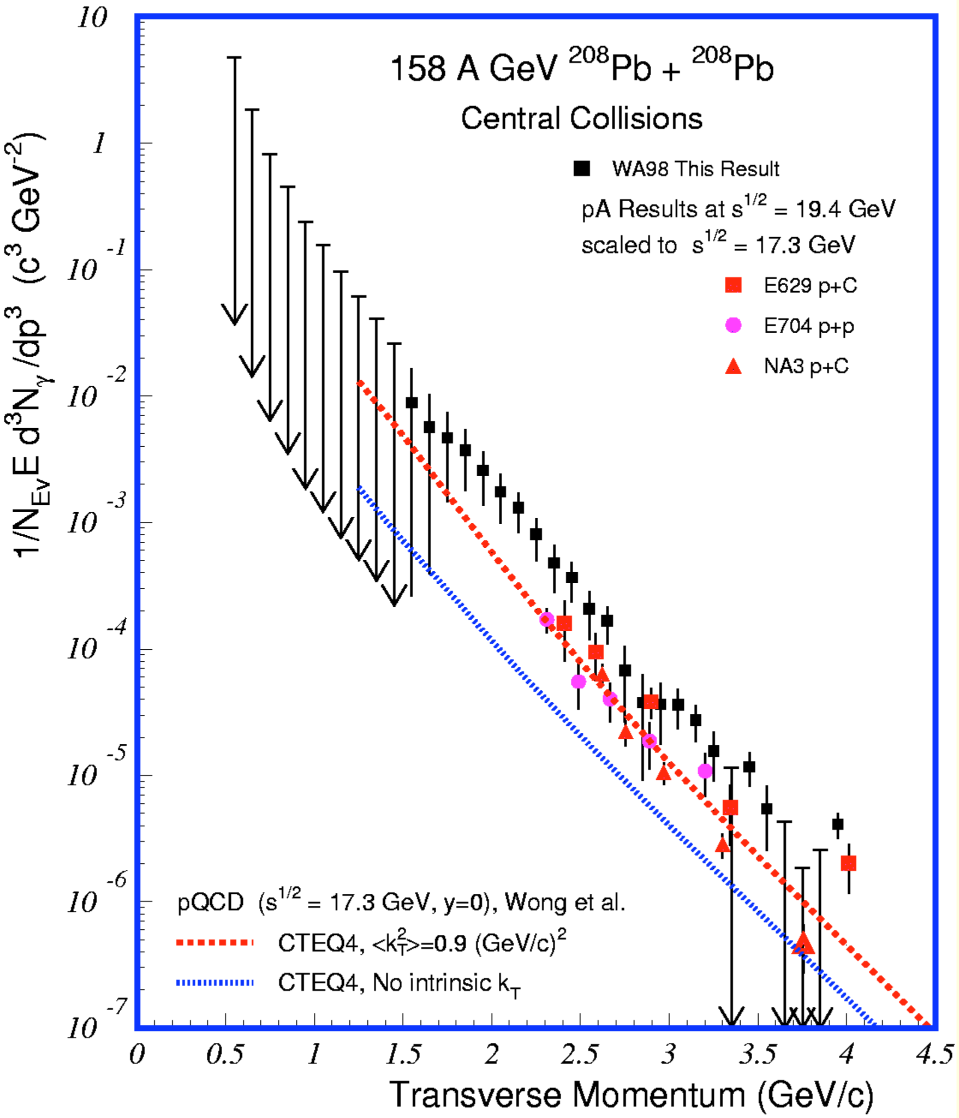
Central Pb+Pb: A Direct γ Signal !



- Compare to proton-induced prompt γ results:
  - Assume hard process - scale with the number of binary collisions (=660 for central).
  - Assume invariant yield has form $f(x_T)/s^2$ where $x_T=2p_T/s^{1/2}$ for $s^{1/2}$-scaling.
- Factor ~2 variation in p-induced results.
- For Pb+Pb, similar γ spectral shape, but factor ~2-3 enhanced yield.

WA98 nucl-ex/0006007, PRL 85 (2000) 3595.

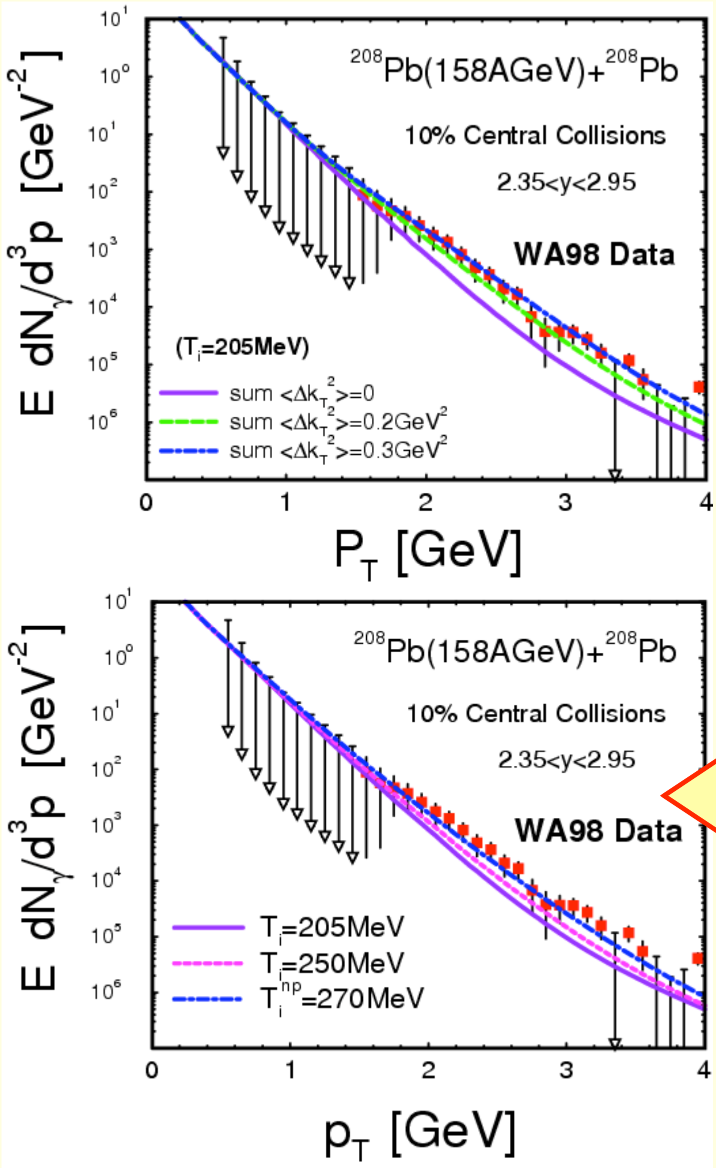
Direct γ: Comparison to pQCD Calculation



WA98 nucl-ex/0006007, PRL 85 (2000) 3595.

- NLO pQCD calculations factor of 2-5 below $s^{1/2}$ =19.4 GeV p-induced prompt γ results.
- But p-induced can be reproduced by effective NLO (K-factor introduced) if intrinsic k_T is included.
- Same calculation at $s^{1/2}$=17.3 GeV reproduces p-induced result scaled to $s^{1/2}$ =17.3 GeV
- Similar γ spectrum shape for Pb case, but factor ~2-3 enhanced yield.

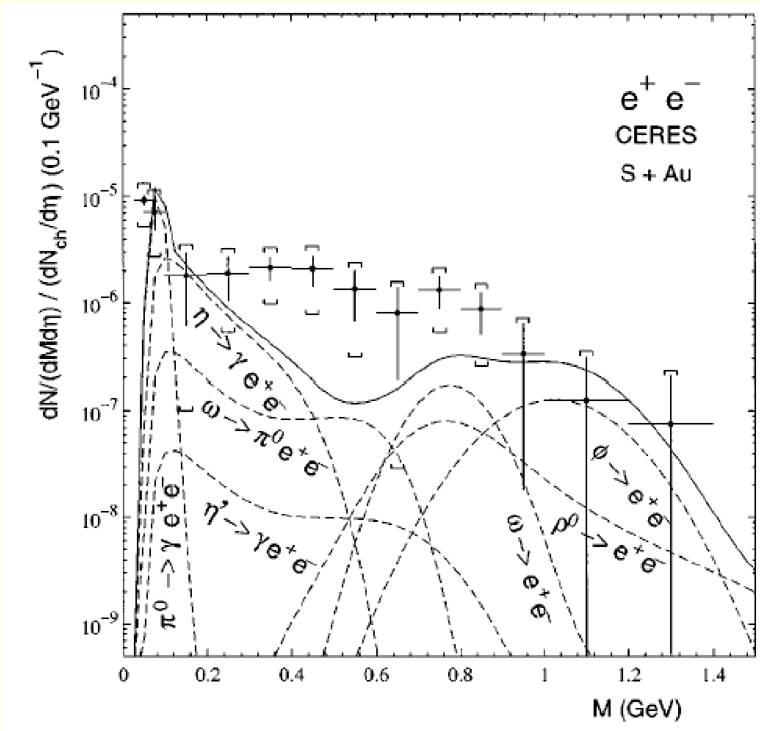
WA98 Interpretation: T or k_T ?

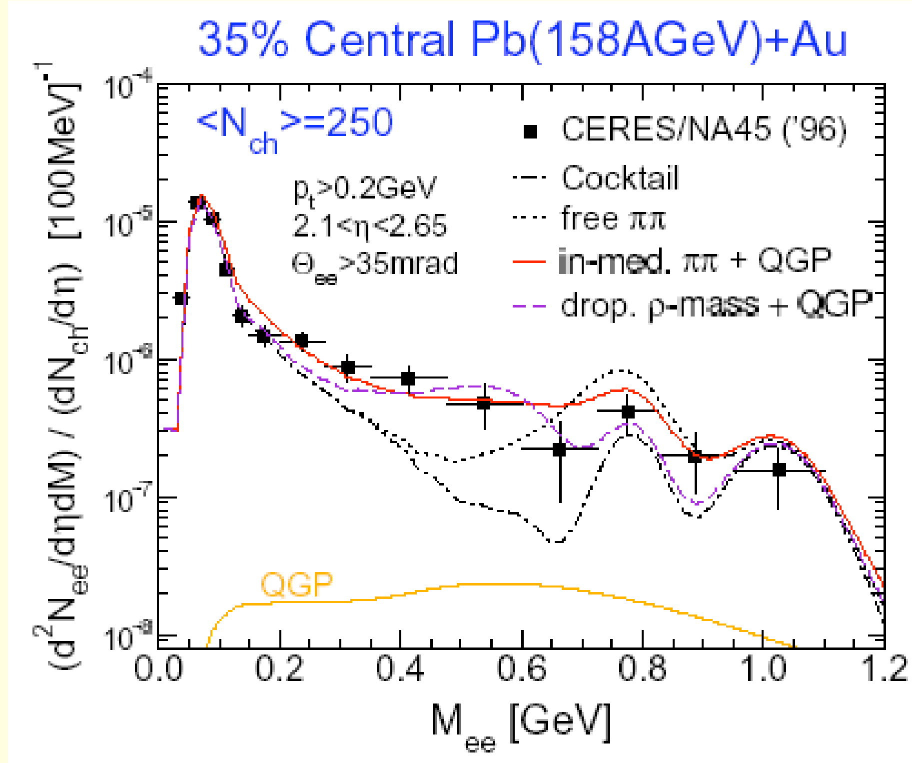


- QGP + HG rates convoluted with simple fireball model plus pQCD hard photons
- Data described with initial temperature T_i=205 MeV + some additional A+A nuclear k_T broadening (Cronin-effect)
- Data also described without k_T broadening but with high initial temperature (T_i=270 MeV)

Turbide, Rapp, Gale,
Phys. Rev. C 69 (014902), 2004

Continuum Dileptons at SPS: CERES/NA45





Low-mass dileptons observed in S+Au at a rate above Dalitz decays.

"The plot that launched a thousand papers." 368 citations actually (Cf: 445+-65 pairs)

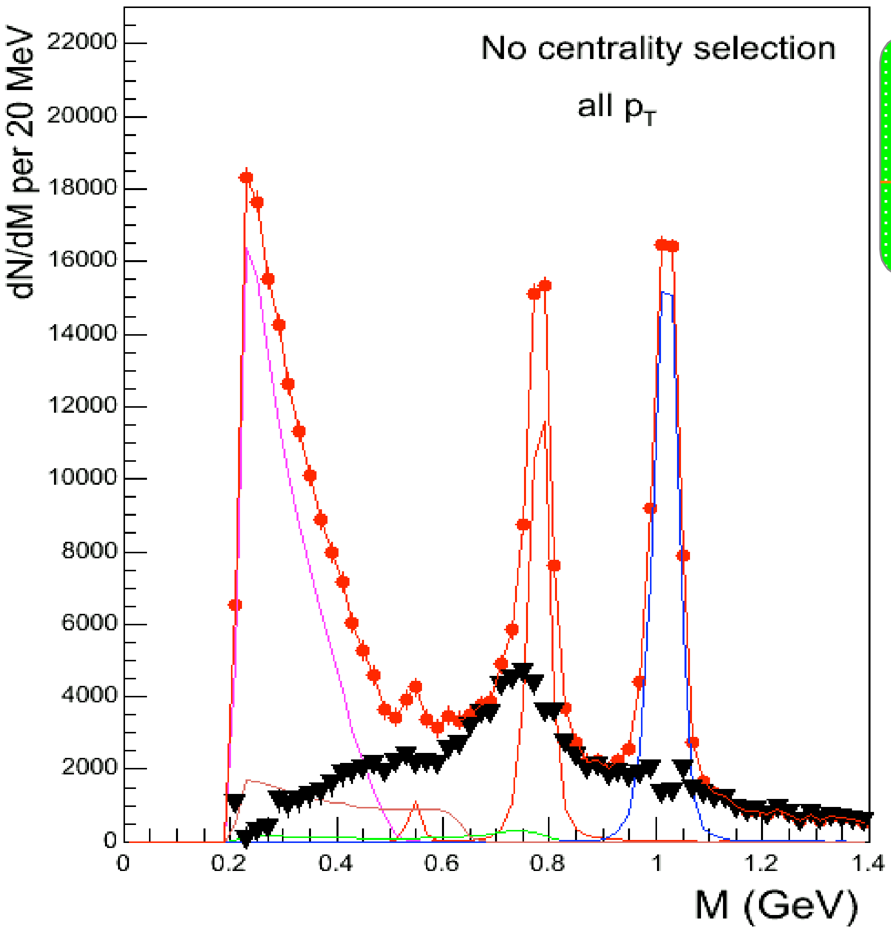
CERES PRL 75, 1272 (1995)

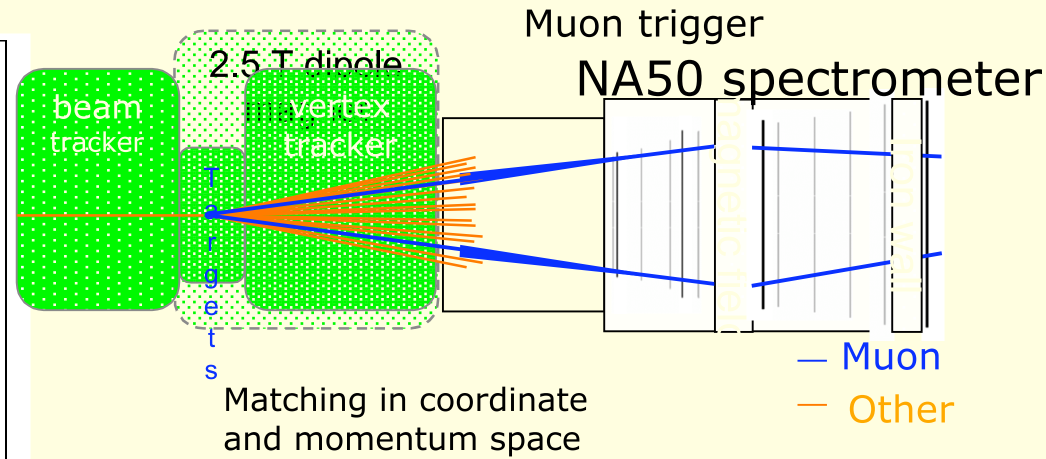
Originally thought to be the result of restoration of chiral symmetry in QGP.

Current wisdom is that a dense hadron gas can produce the excess.

R. Rapp hep-ph/0201101

NA60: Low Mass μ-pairs In+In 158A GeV





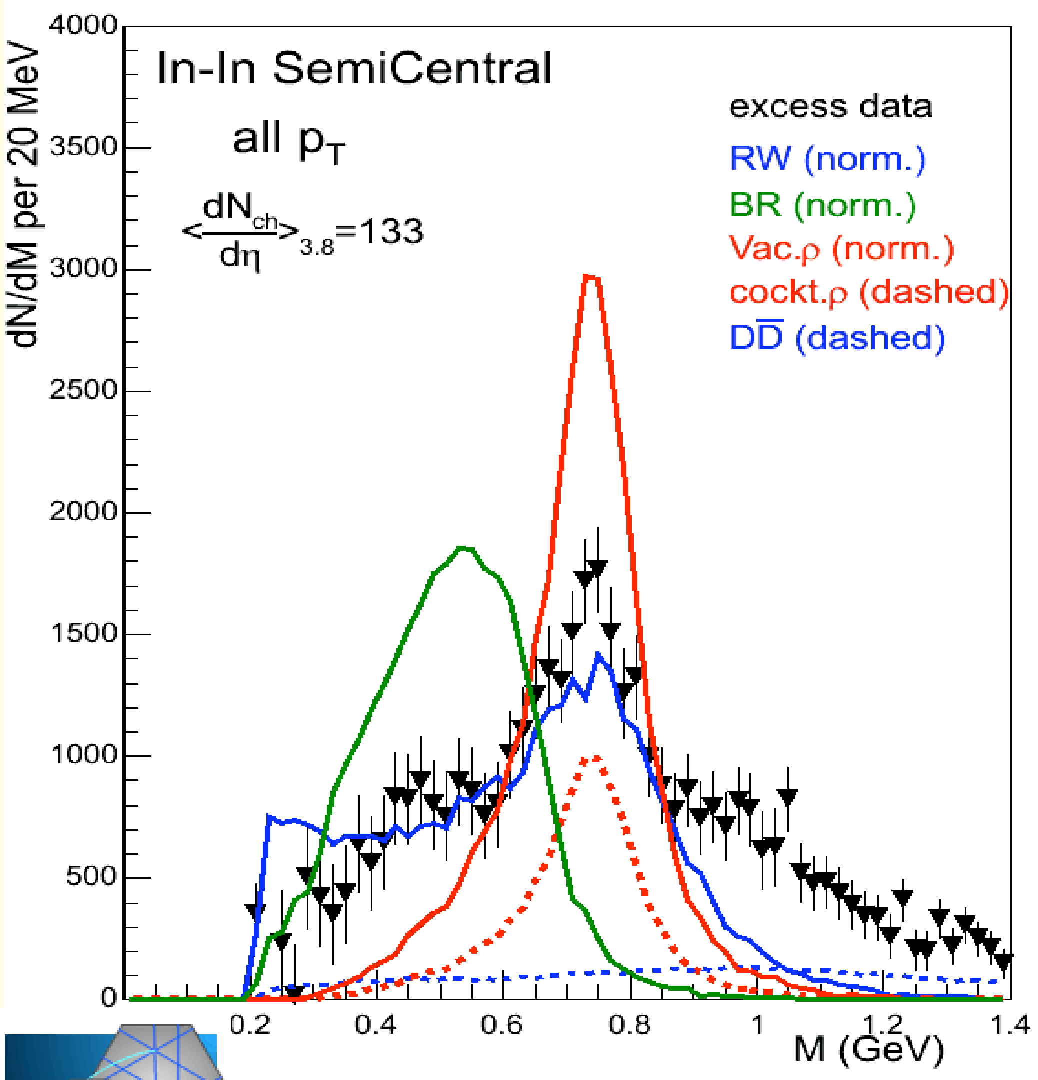
- **ω and ϕ: yields fixed to obtain, after subtraction, a smooth underlying continuum**

- **η: set upper limit by "saturating" the yield in the mass region 0.2–0.3 GeV**
  ⇒ leads to a lower limit for the excess at low mass

Data taken 2003

From E.Scomparin, QM2005

Low mass: Comparison with models

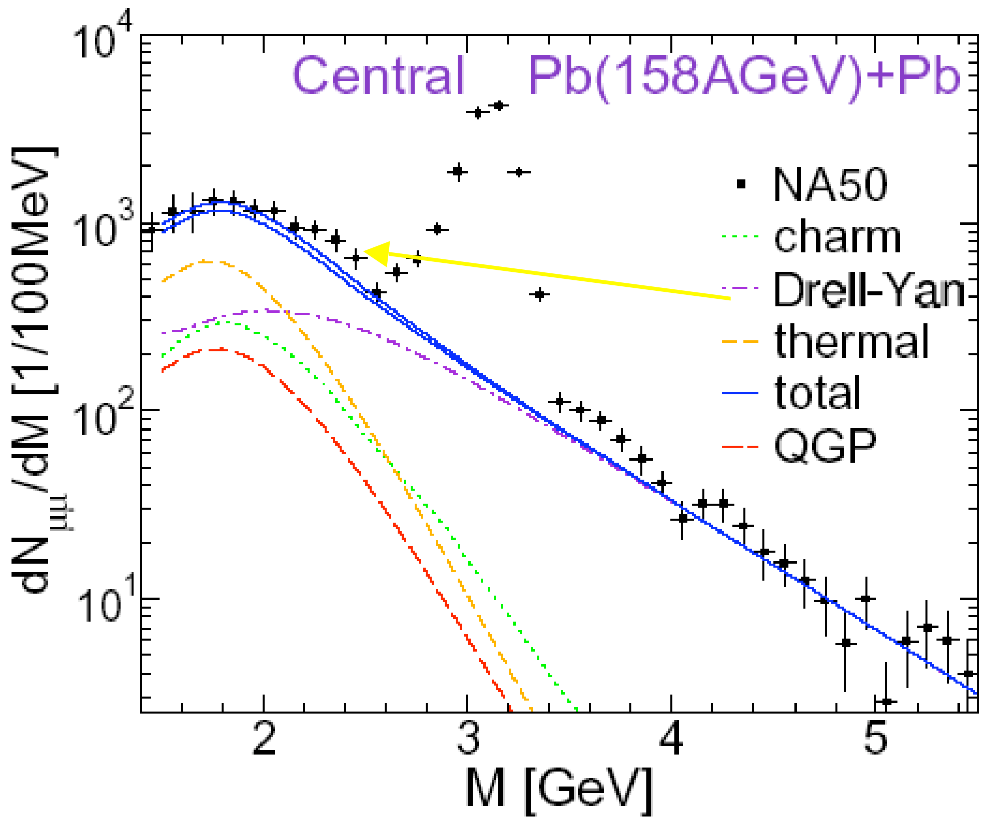


Predictions for In+In by Rapp et al. (2003) for $\langle dN_{ch}/d\eta \rangle = 140$

Theoretical yields folded with NA60 acceptance and normalized to data in the mass window $m_{\mu\mu} < 0.9$ GeV

- **Excess shape consistent with broadening of the ρ (Rapp-Wambach)**
- **Models predicting a mass shift (Brown-Rho) ruled out**
  (NA60 statement!)

Continuum Dileptons in Intermediate Mass Region (IMR) 1<M < 3 GeV : NA50



NA50 Eur Phys J C14 (2000) 443

R. Rapp hep-ph/0201101

Dileptons in the intermediate mass range $M_\phi < m_{\mu\mu} < M_{J/\Psi}$ are also candidates for thermal radiation.

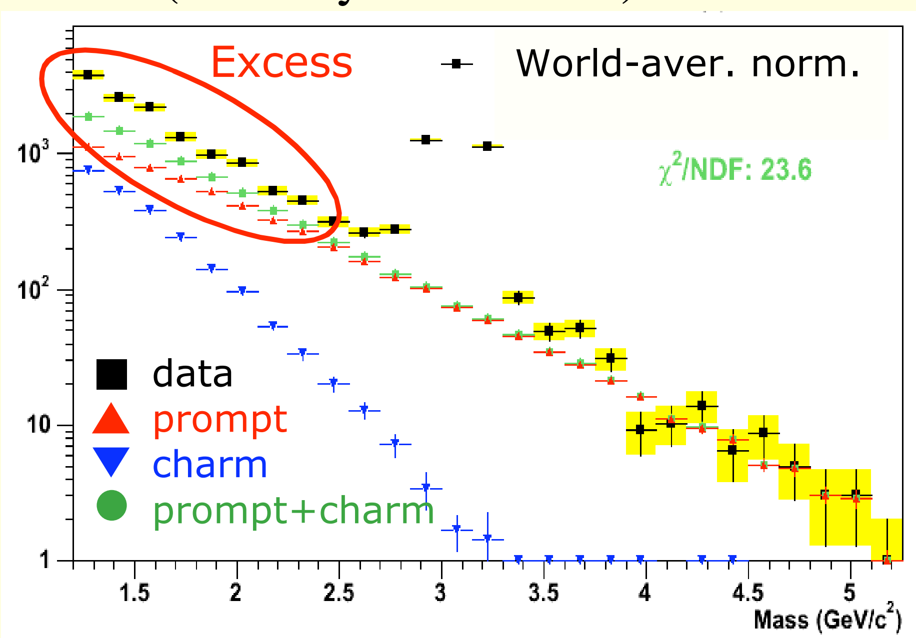
Apparent excess by factor of ~2, can be explained as thermal from hadron gas phase.

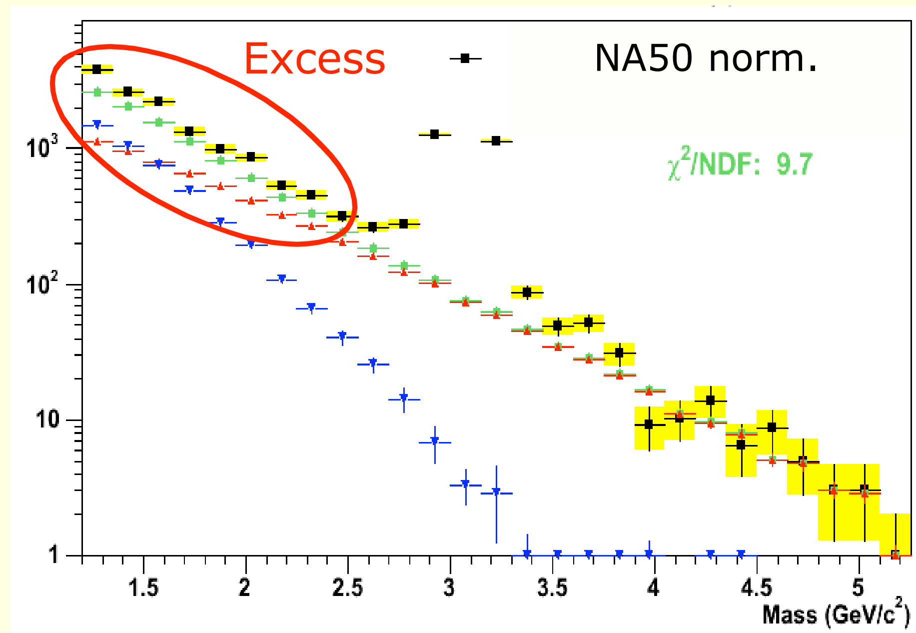
But there is an alternative explanation as enhanced production of open charm.

NA60 IMR: Is an excess present ?

- Open charm and Drell-Yan generated with PYTHIA
- Drell-Yan normalization fixed using the high mass region
- Open charm normalization: use
  - ⇒ NA50 p-A result (better control of systematics related to μμ channel)
  - ⇒ World-average cc cross section (based on direct charm measurements)

  (differ by a factor ~ 2)





- **Answer: Yes, an excess in the IMR is clearly present**

  (same order of magnitude as the NA50 result)

IMR: Measuring the muon vertex offset

As in NA50, the mass shape of the In+In excess is compatible with open charm ⇒ not conclusive, muon offset information needed

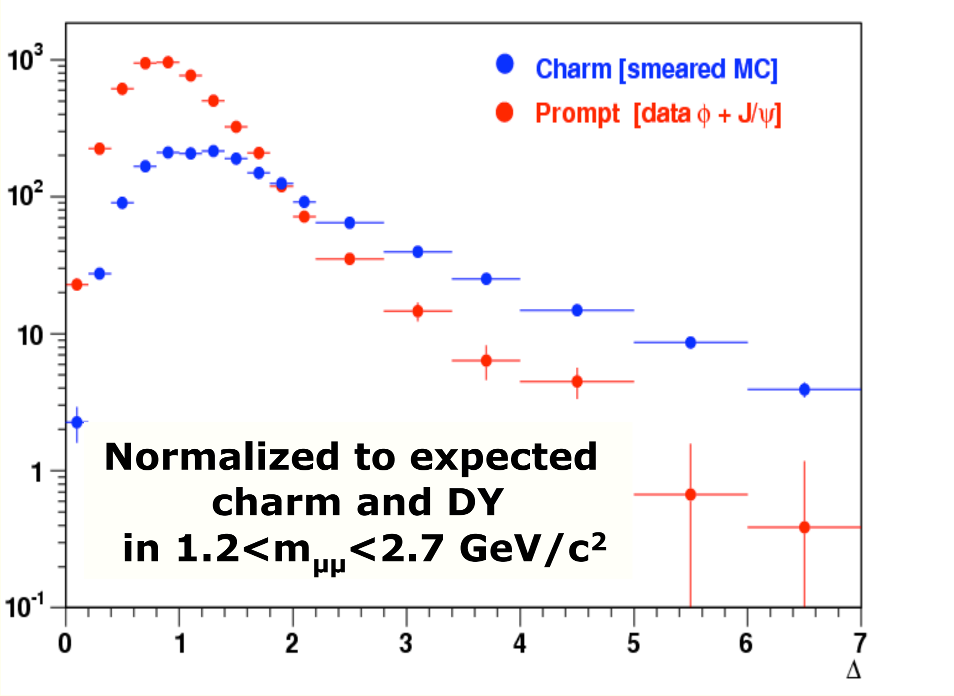
Muons from D -> μ + X do not converge to the interaction vertex

Typical offset of muons: **D^+ : $c\tau$ = 312 μm**
D^o : $c\tau$ = 123 μm

- **Muon offsets: ΔX, ΔY between the vertex and the track impact point in the transverse plane at Z_{vertex}**

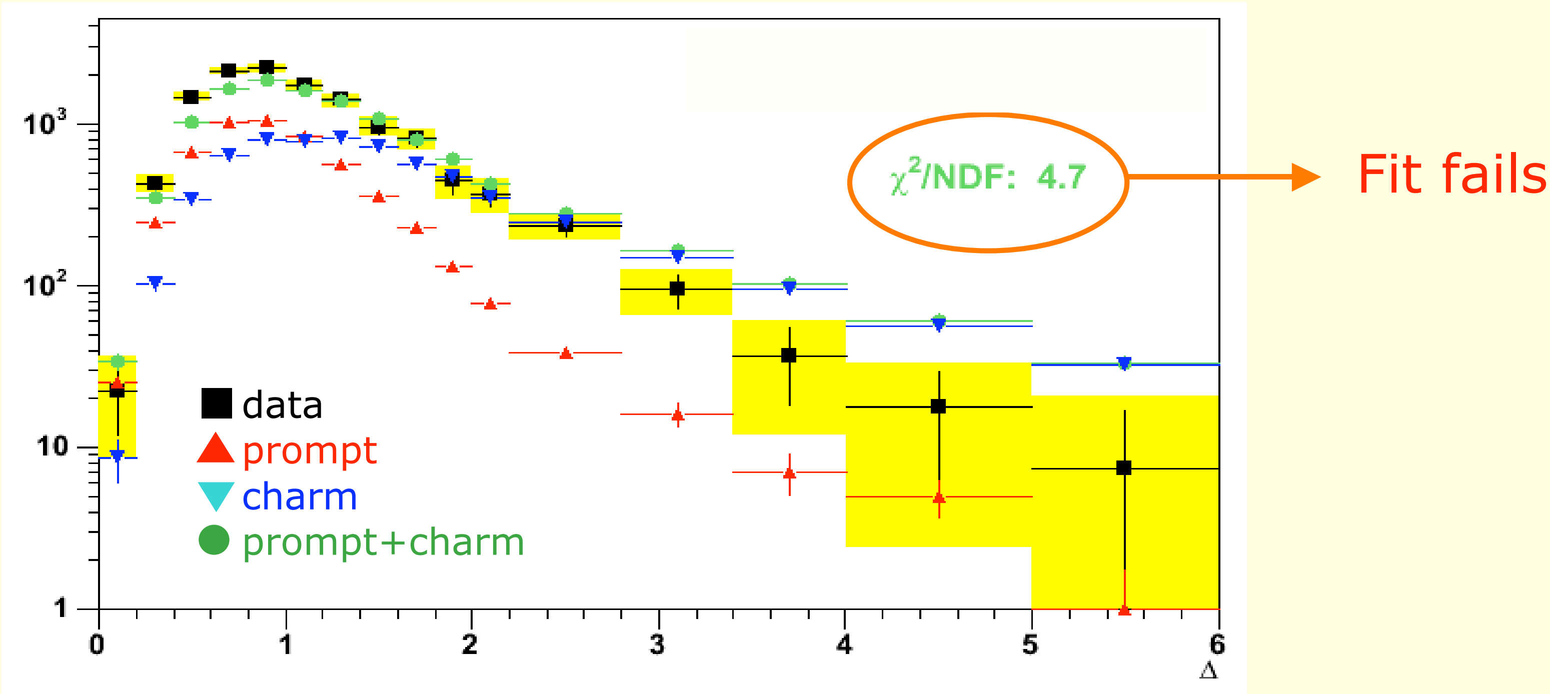
Δ_μ ⇒ offset weighted by the covariance matrices of the vertex and of the muon track

Offset resolution ~ 40-50 μm
(measured with J/ψ data)



IMR: Is the excess due to open charm ?

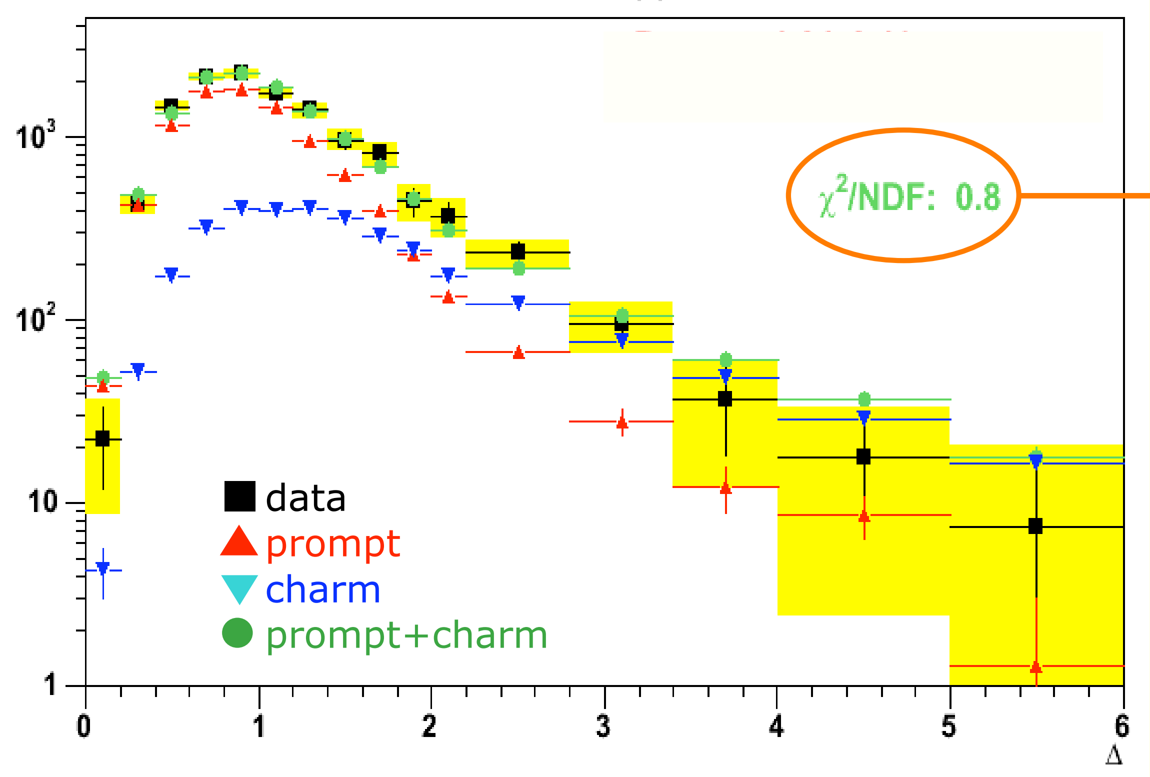
Fit IMR Δ_μ distribution fixing prompt contribution to the expected Drell-Yan yield



Answer: No, the excess seen in In+In is not due to open charm enhancement

IMR: is the excess due to prompt dimuons ?

⇒ Fit IMR Δ_μ distribution fixing open charm contribution to the expected value (from NA50 p+A)



Fit converges, good χ^2

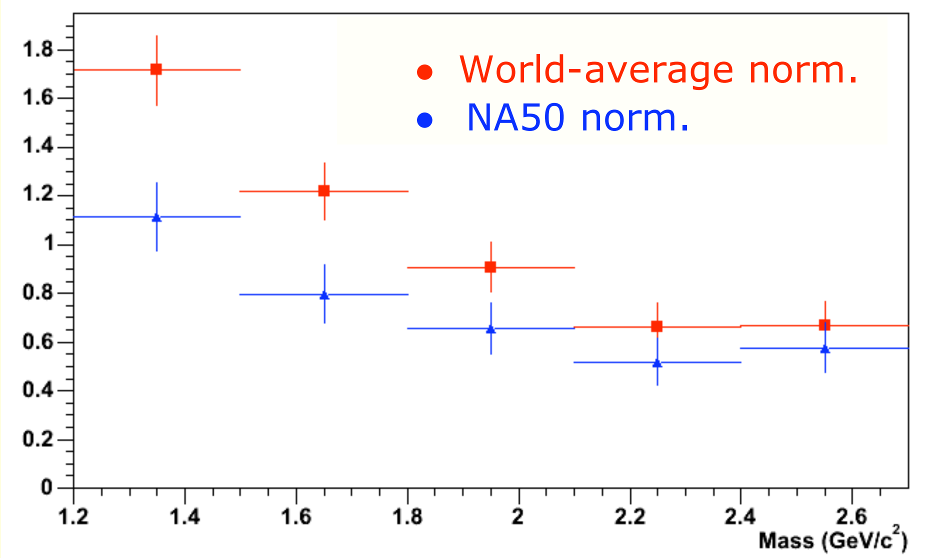
$$\frac{\text{Meas. prompt}}{\text{Exp. prompt}} = 1.91 \pm 0.11$$

(2.10 ± 0.07 when world-average norm. is used)

Answer: Yes, the excess seen in In+In is prompt, not charm.

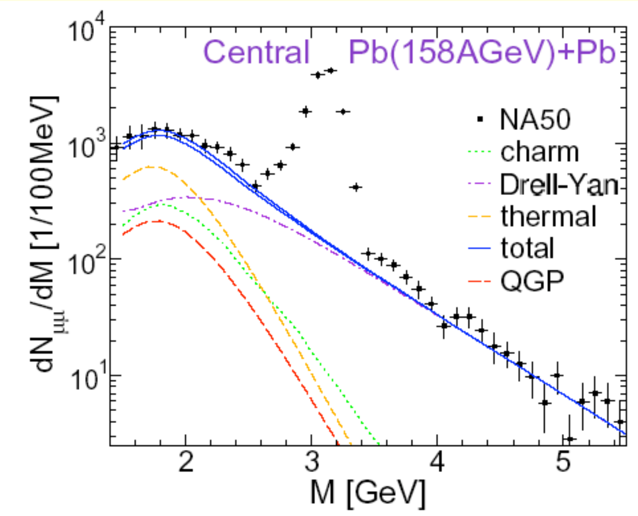
Mass shape of the IMR excess

Excess/Drell Yan



The mass distribution of the excess is steeper than Drell-Yan (and flatter than open charm) **-**

Thermal origin?
Maybe, but dominated by HG.
But sensitive to T_i! (T_i = 220MeV)

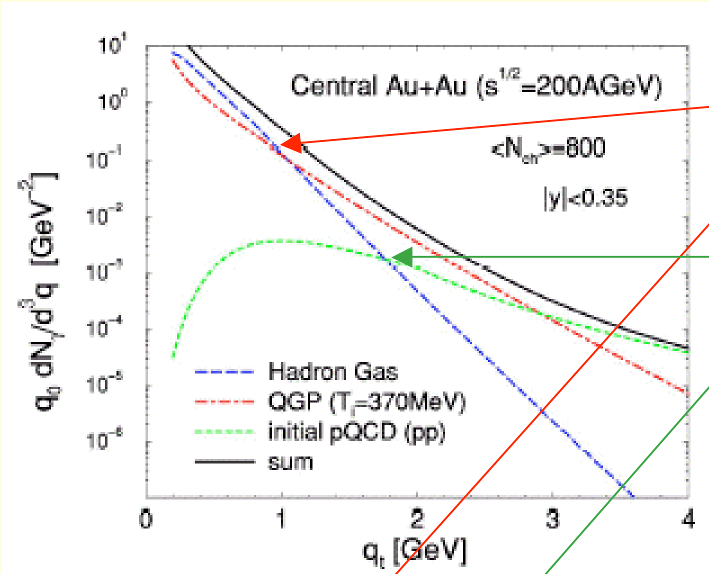


R. Rapp hep-ph/0201101

Conclusions from SPS measurements

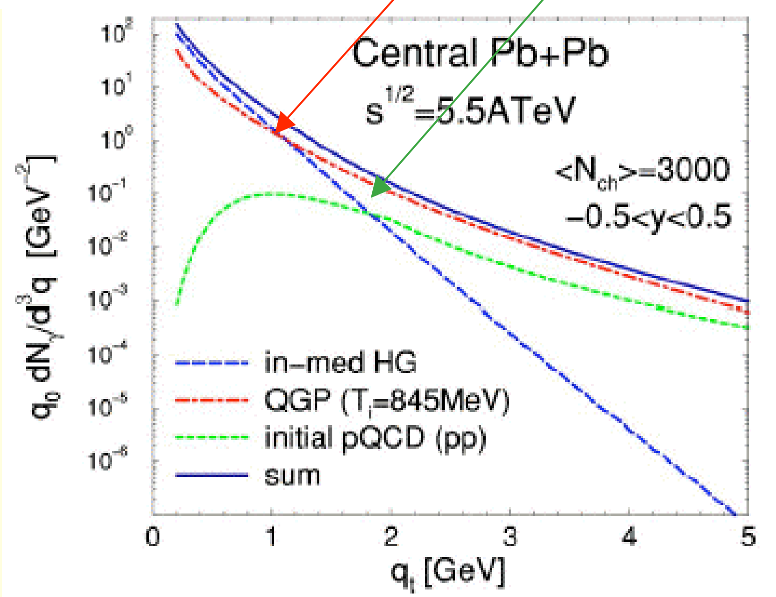
- **Real and virtual γ excesses observed, but many sources of theoretical uncertainty:**
  - pQCD γ reference: intrinsic k_T, k_T broadening
  - Non-thermal contributions
  - QM γ rates: (under control!)
  - HM γ rates: in-medium masses
  - Hydrodynamic evolution: flow
- **Further experimental constraints:**
  - Hadron spectra to fully constrain hydro calculations
  - Need p+p and pA results to validate pQCD calculations
- **Improved understanding from RHIC measurements should feedback to improve understanding at SPS**
  - p+p and p+A measurements
  - Low energy runs

Thermal γ: Expectations for RHIC & LHC

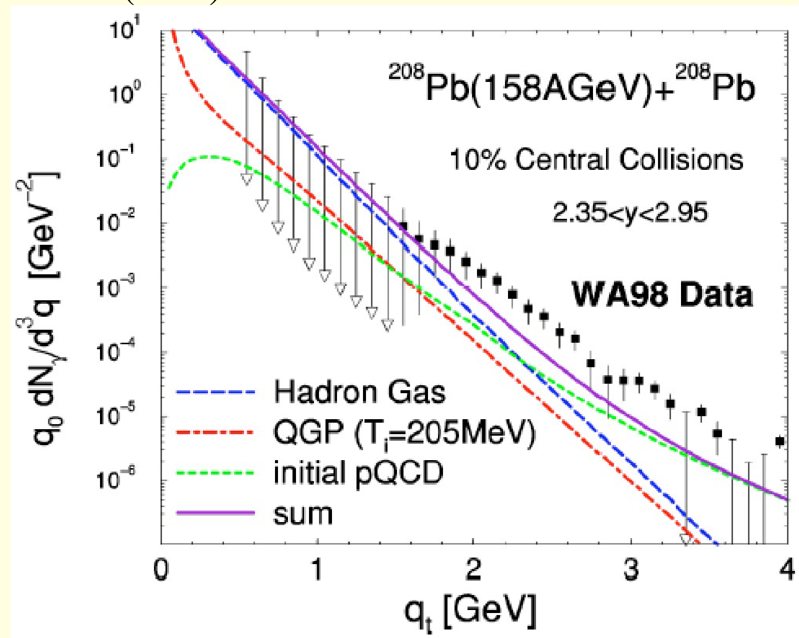


- **At RHIC & LHC the HG contribution dominates over the QGP contribution for p_T<1 GeV/c**
- **At RHIC & LHC (&SPS) the HG contribution dominates over the pQCD contribution for p_T< 2 GeV/c**
- **Window to see QGP radiation dominantly in region 1 GeV/c <p_T< ~3(RHIC) ~5(LHC) GeV/c?**

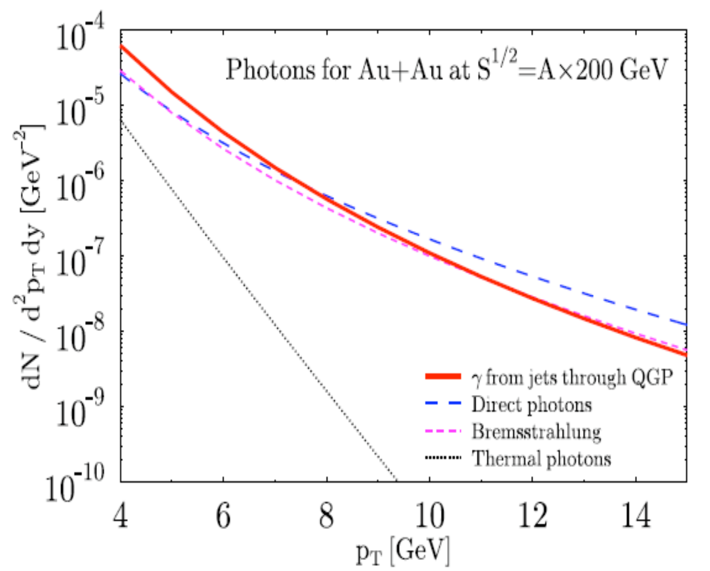
Turbide, Rapp, Gale PRC 69 (2004) 014903



T.C.Awes

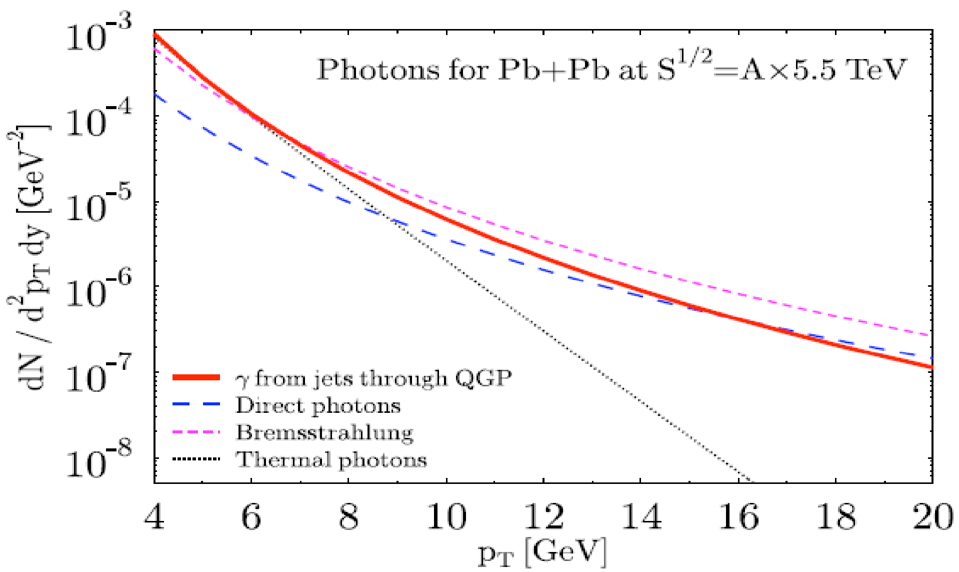


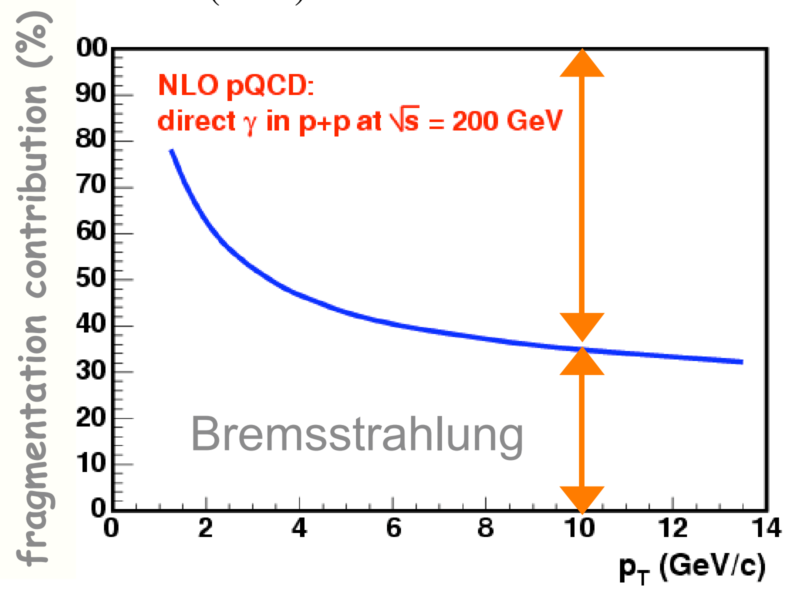
Direct γ: Other effects for RHIC & LHC



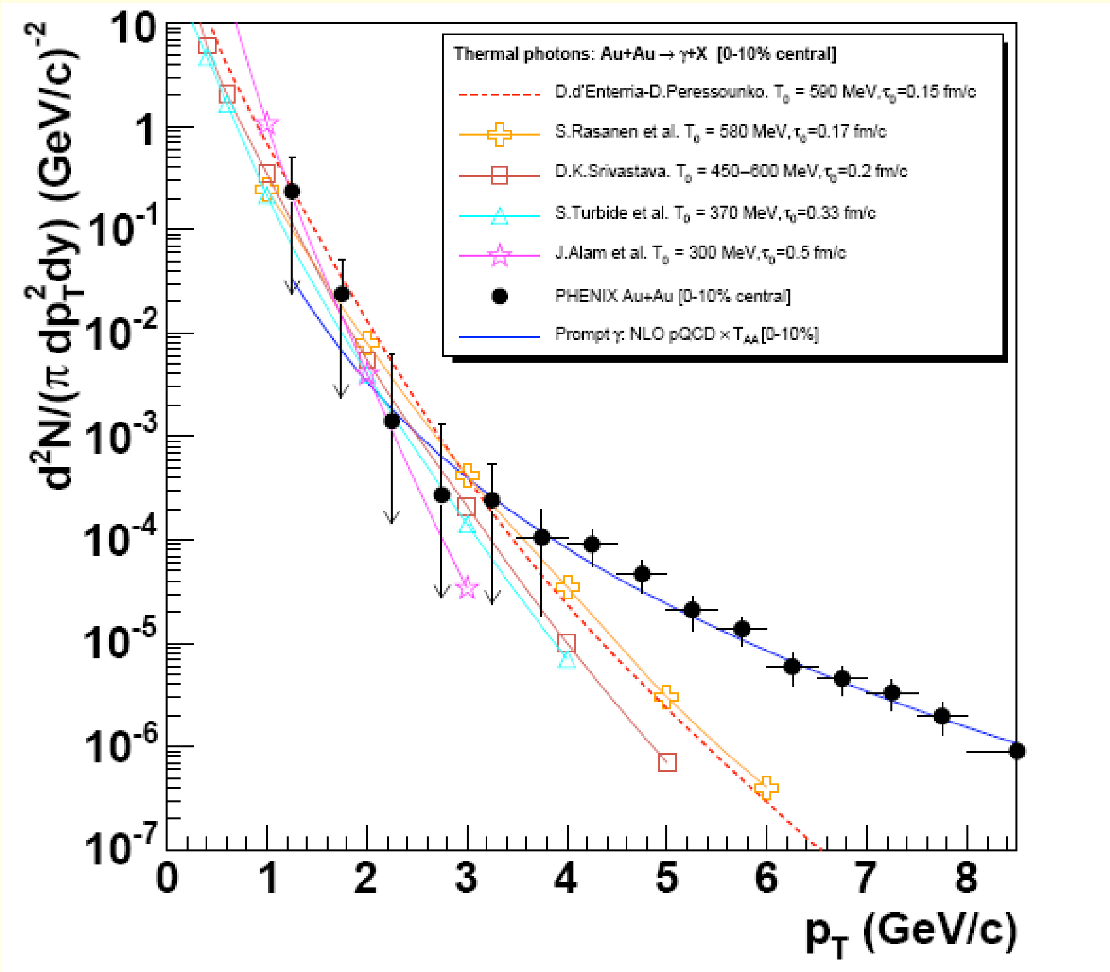
- At low p_T a large fraction of direct γ due to Bremsstrahlung in the Fragmentation process. At RHIC & LHC parton energy loss should reduce this contribution.
- On the other hand, one expects additional γ radiation from jet due to passage through QGP. This contribution is expected to dominate below 6-8 GeV/c.
- We've lost the pQCD γ "reference" again!

Fries,Muller,Srivastava PRL 90 (2003) 132301





Measuring Thermal Photons at RHIC…

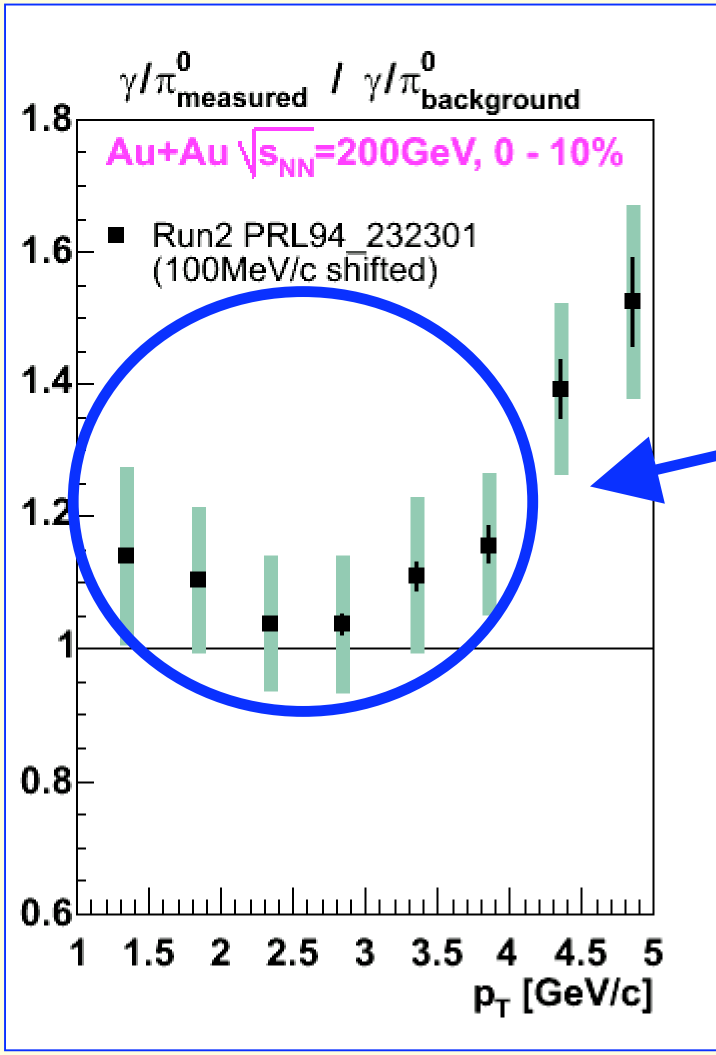


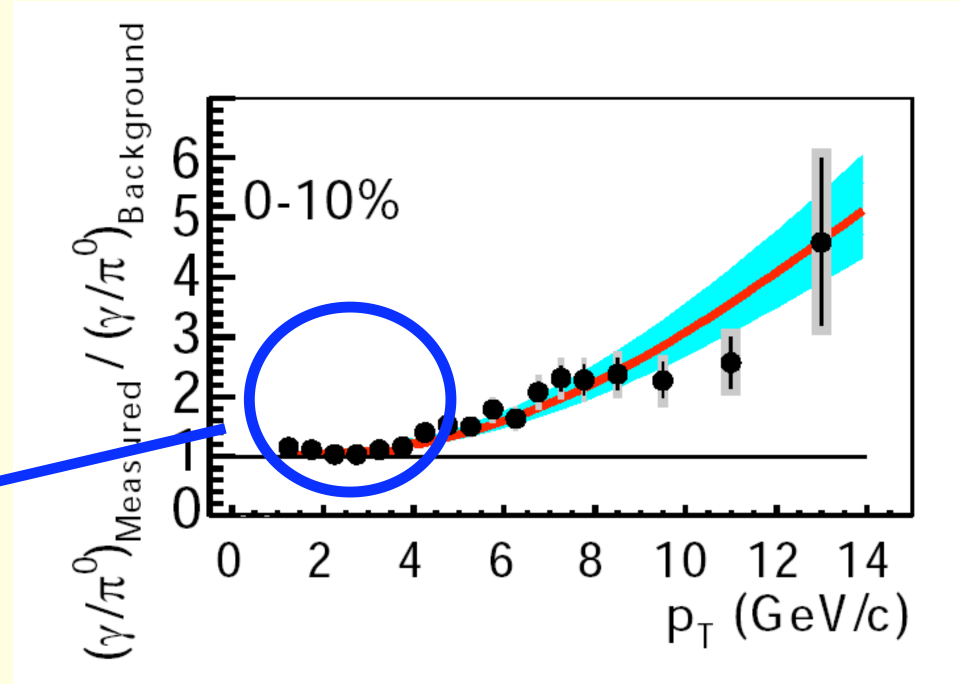
PHENIX PRL 94 (2005) 232301

- **NLO pQCD predictions consistent with observed excess to low p_T**
- **What about modifications to Bremsstrahlung contribution???**
- **Wide range of thermal “predictions” (T_i= 300-600 MeV!) consistent with measurement.**

- **Experimental uncertainties need to be improved significantly.**
- **Theoretical “freedom” must be decreased also.**

Limitations of Statistical Method

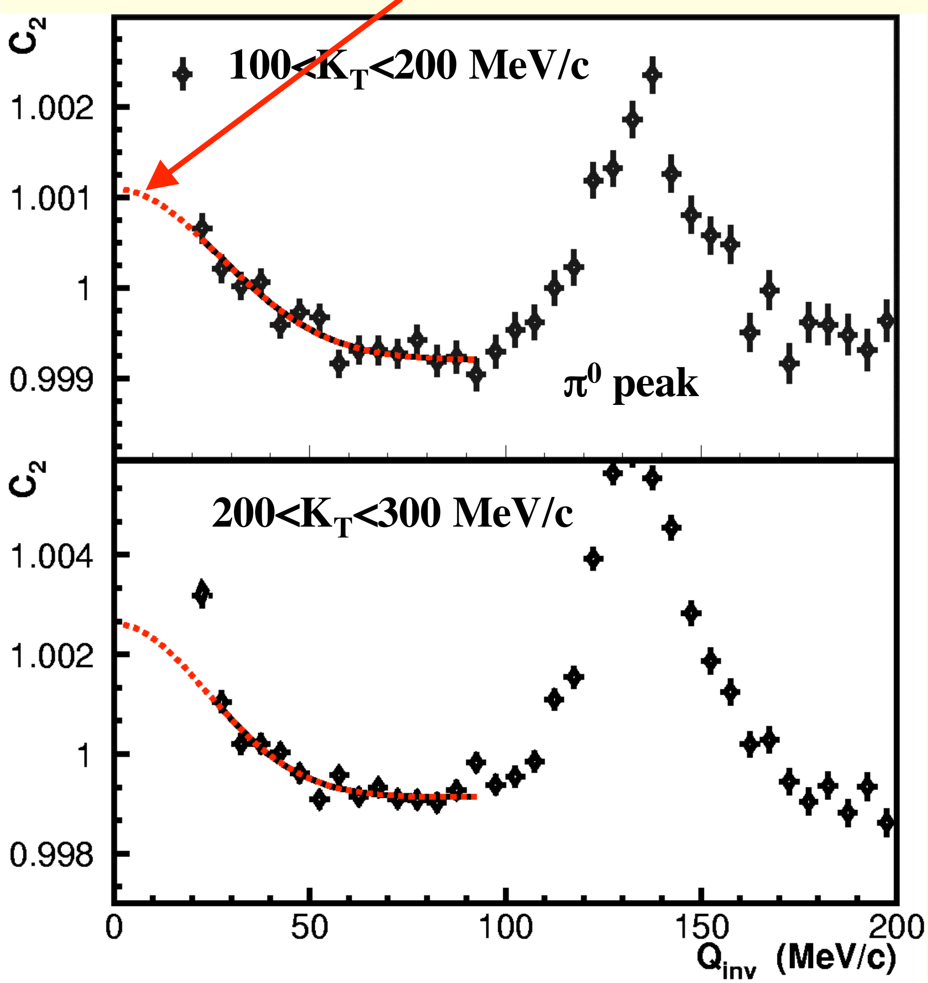




- **Excess is small (~10%) in comparison to γ from decays. If errors reach R=1 then lower error on γ yield extends to zero.**
- **Need to improve errors.**
- **Alternative methods:**
  - * **Virtual photons (Torsten's talk)**
  - * **γ–γ HBT**

Direct γ Yield via γ–γ HBT Correlations: Pb+Pb@SPS

$C_2 = A[1+\lambda \exp(-Q^2_{inv} R^2_{inv})]$



Pure BE effect - no Coulomb, no FSI

2λ = fraction of γ pairs which are Direct (2 polarizations)

Direct γ $= \sqrt{2\lambda} *$ Total γ

With calorimeter only possible at low K_T since $Q_{inv} \sim K_T \times \Delta L$

For close shower separation ΔL background sources from:

> False splitting of showers

> Photon conversions

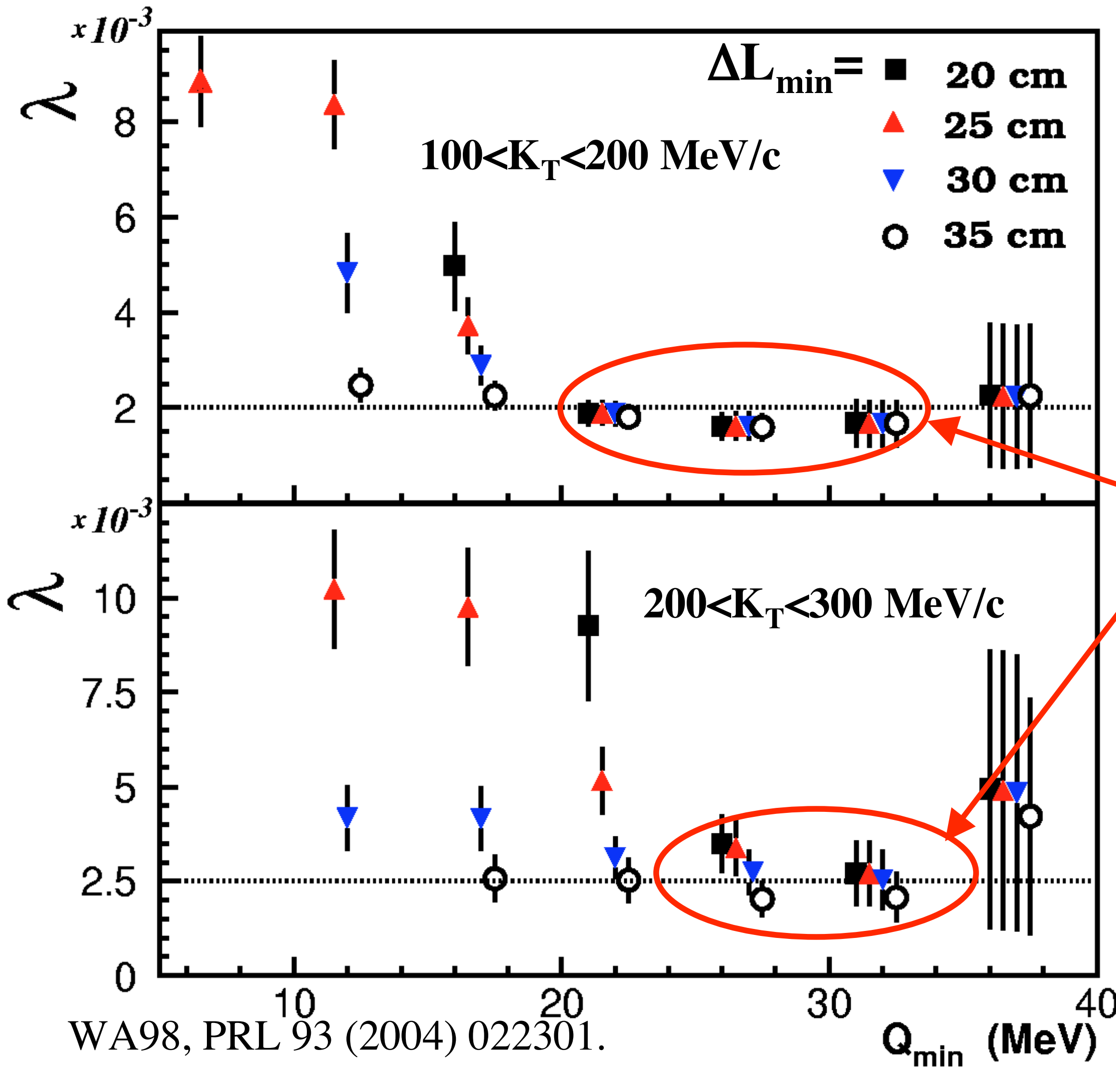
A "bold" calorimeter measurement!!!

Must make min distance cut ΔL_{min}

$K_T = |\vec{p}_1 + \vec{p}_2| / 2$

WA98, PRL 93 (2004) 022301.
Analysis: D.Peressounko

ΔL_{min} Dependence of $\gamma-\gamma$ Correlation Strength λ



WA98, PRL 93 (2004) 022301.

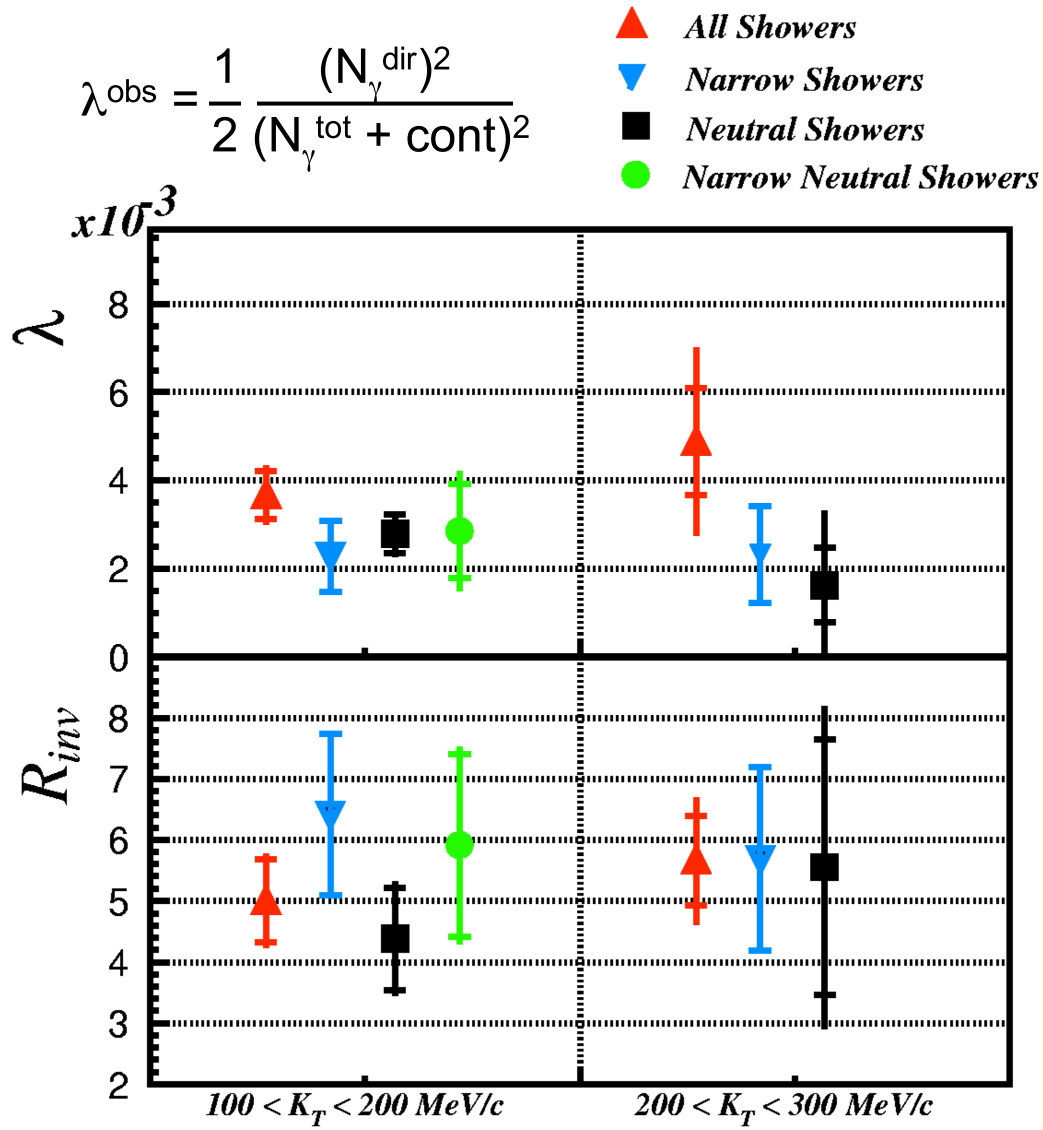
Since $Q_{inv} \sim K_T \times \Delta L_{min}$ a cut on ΔL_{min} has similar effect as restricting the fit to region above Q_{min}.

Stable fit results with $\Delta L_{min} > 35$cm cut or by restricting Q_{inv} fit region.
Similar result for $R_{inv.}$

Implies region free of background and detector effects.

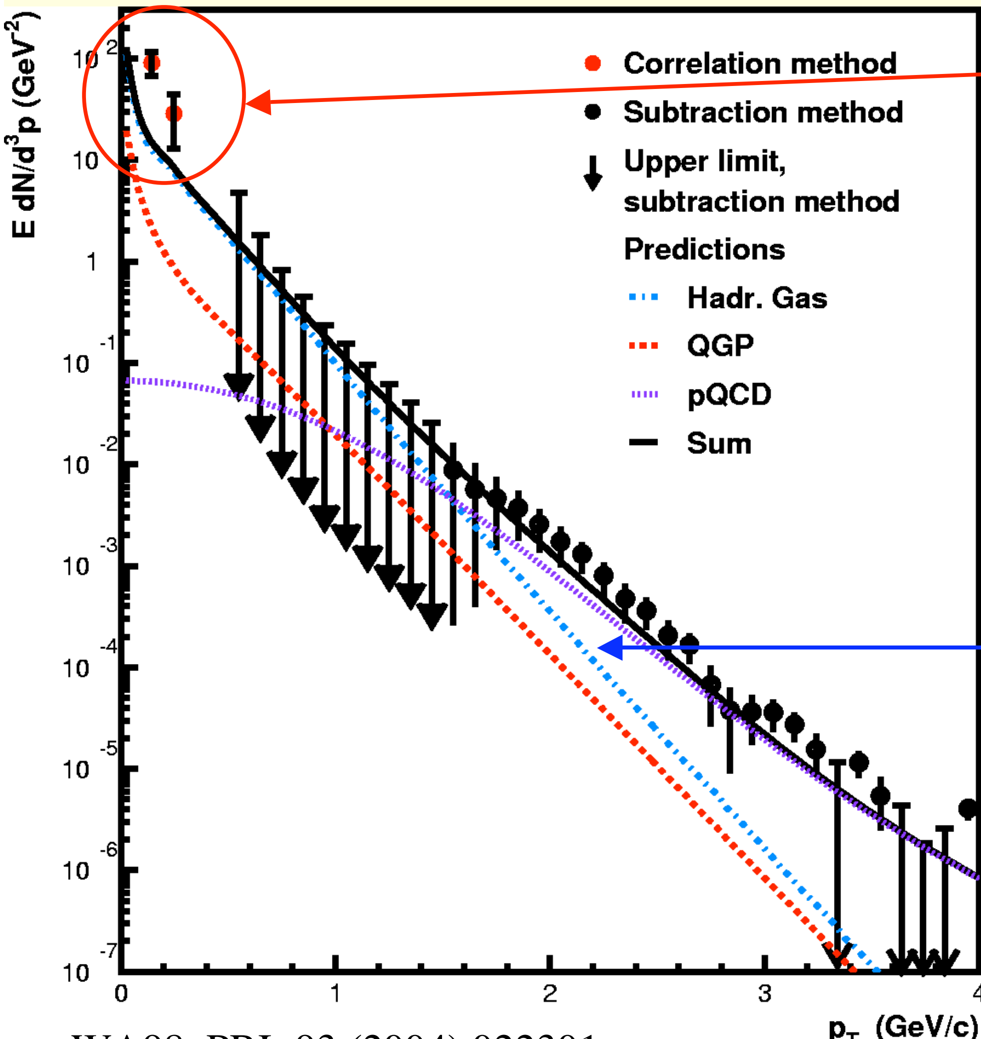
Dependence of γ–γ HBT Parameters on γ PID

$$\lambda^{obs} = \frac{1}{2}\frac{(N_\gamma^{dir})^2}{(N_\gamma^{tot} + \text{cont})^2}$$



- **Vary γ shower identification criteria to vary non-γ background fraction:**
  - **37% and 22% charged bkgd for 2 K_T bins with All showers**
  - **16% and 4% with Narrow showers**
  - **<2% with charge veto**
- **If correlation due to background, it should be strongly affected by PID cuts.**
- **Observe no dependence on PID cuts which indicates a true γ–γ correlation.**
- **R_{inv} ~ 5-6 fm**
- **Compare $R_{inv}(\pi^-)$=6.6-7.1 fm**

Direct γ Yield via $\gamma-\gamma$ HBT Correlations



WA98, PRL 93 (2004) 022301.

Two new low p_T direct γ points from λ of $\gamma-\gamma$ correlation.

Fireball model predictions:
Turbide, Rapp, Gale PRC 69 (2004) 014903. Latest in Hadronic rates, pQCD + k_T broadening, T_i=205 MeV, T_c=175MeV

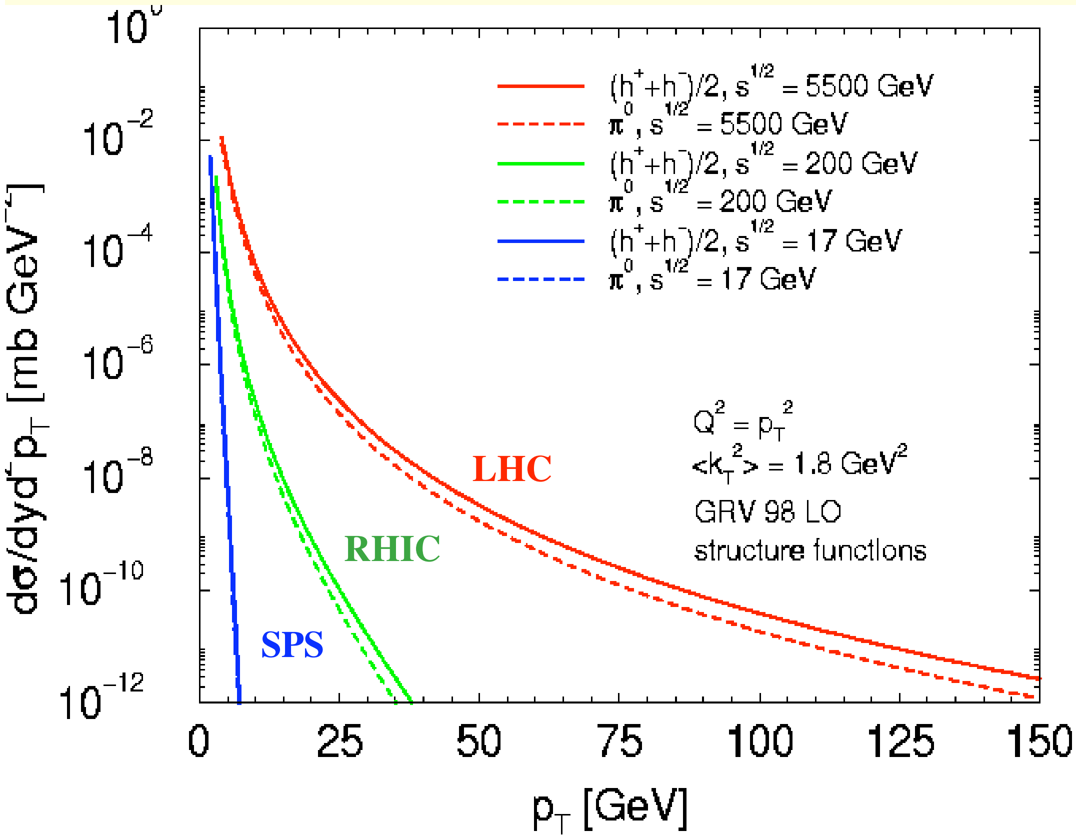
Low p_T region dominated by Hadron Gas phase. Additional Brems. in HG (Rapp et al.).

Better way to do this is to use γ+(e^+e^-) HBT - PHENIX.

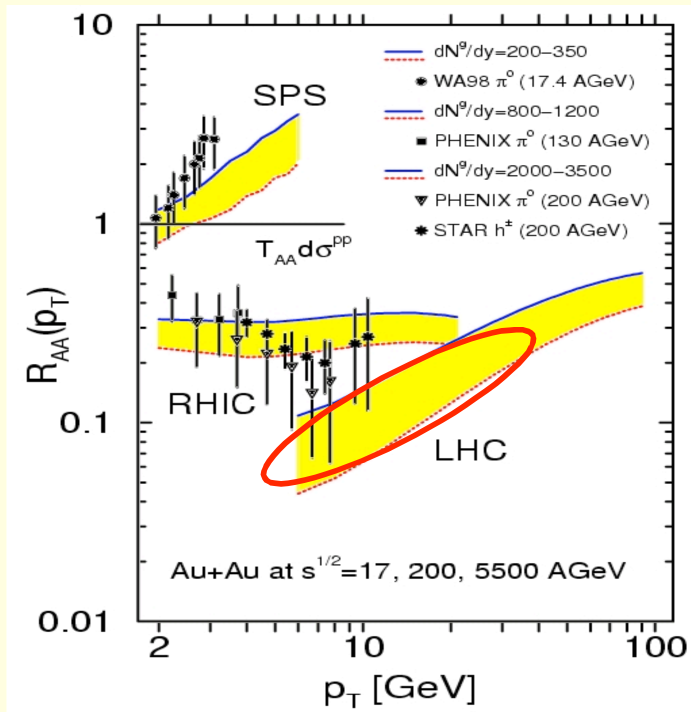
Direct γ, π^0 at LHC

Large direct γ rates to ~100 GeV/c, large π^0 suppression expected.

Direct γ measurements will provide a powerful probe at LHC, especially to diagnose the jet quenching phenomena.



M.Gyulassy, I.Vitev, (pQCD). QM'92



I.Vitev, M.Gyulassy
PRL 89 252301 (2002)

Summary and Conclusions

- Direct γ signal observed at SPS in Pb+Pb collisions possibly explained by EOS with QGP, but also consistent with HG - But large #d.o.f.! Problem: - poor pQCD understanding: intrinsic k_T effects, etc.

- Taken together, the direct γ signal and intermediate mass dilepton excess in central A+A collisions at SPS can be explained consistently with thermal emission, dominantly from HG, but with initial temperature of T_i~220 MeV, i.e. $T_i > T_c$

- Direct γ signal observed at RHIC in Au+Au scales with N_{Binary}
  - NLO pQCD works too well, given other expected effects.
  - Extraction of thermal γ component will be very difficult, due to small signal and large competing effects on fragmentation contribution.

- Studies of jet energy loss with γ+jet will be "the measurement" to do at LHC.